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SNPO-C

MASTER

REON
SACRAMENTO PLANT

REPORT NO. RN-S-0110

TO

AEC-NASA SPACE NUCLEAR PROPULSION OFFICE

MARK III
TURBOPUMP ASSEMBLY PERFORMANCE
TEST RESULTS (U)

CONTRACT SNP-1 SEPTEMBER 1964 NERVA PROGRAM

AEROJET
GENERAL TIRE
GENERAL

(0718)

AEROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA

[redacted]

MASTER

Report RN-S-0110

ABSTRACT

This report presents a discussion on the performance of the NERVA turbopump assembly, with particular emphasis on test results obtained with the Mark III Mod 3 configuration.

Approved by:

W. D. Stinnett
NERVA Technical Systems Manager
REON

FOREWORD

This report fulfills in part the portion of Contract SNP-1, Subtask 1.2, requiring special technical reports on analysis of Mark III TPA test data and results of tests.

TABLE OF CONTENTS

APPENDIXES

I. SUMMARY AND CONCLUSIONS

The LH_2 pumping performance of the Mark III Mod 3 turbopump was documented at steady-state conditions with a straight inlet pipe as follows:

1. Shaft speeds between 10,000 and 24,200 rpm.
2. Q/N values between diffuser stall limits and 0.475 gal./rev.
3. $NPSH/N^2$ values between 0.10×10^{-6} and 5.0×10^{-6} ft/rpm^2.

The LH_2 pumping efficiency of the Mark III Mod 3 turbopump in conjunction with the alternate 1 centerbody inlet was 4.5 to 8% below that obtained with the straight inlet pipe with the same pump components over the given range of conditions.

Conditions at which pumping data were obtained with the centerbody inlet were as follows:

1. Shaft speeds between 18,500 and 24,700 rpm.
2. Q/N values between 0.25 and 0.32 gal./rev.
3. $NPSH/N^2$ values between 0.2×10^{-6} and 4.0×10^{-6} ft/rpm^2.

Turbine efficiency and flow parameter (W T/P) values were documented, using data from ambient temperature GH_2 tests for two-and three-stage turbines.

I. SUMMARY AND CONCLUSIONS (Cont.)

The pumping performance with LH_2 was not the same as that experienced while pumping water: at the same $NPSH/N^2$ and Q/N values, the $\Delta H/N^2$ and pump efficiency values differed. (Test results obtained with water as the test fluid were presented in Figure 6 of Report SST 1.2.3-64-R-001 by E K Bair, 9 March 1964.)

The conventional parameters, $\Delta H/N^2$, Q/N, and pump efficiency, do not completely normalize (LH_2 pumping test results) at all conditions: There was an NPSH effect and an additional shaft speed (secondary) effect.

Diffuser stall limits were affected by inducer inlet NPSH values.

Should a centerbody inlet be required, further testing would be required to determine the capabilities of the TPA under different conditions. The present available data with the alternate 1 centerbody inlet is not sufficient to allow the documentation of pump characteristics at high (Q/N = 0.40) and low (Q/N = 0.20) flows and low suction (NPSP = 4 psi) pressures.

Present test plans call for demonstrating pump capabilities at low to high flows and low to high suction pressures, at constant rpm's (N < 15000 rpm). The accumulated data will be used to determine breakaway torque and minimum childown times.

II. <u>DISCUSSION</u>

The performance of the NERVA turbopump assembly while pumping liquid hydrogen (LH_2) and the methods used in arriving at such performance are discussed below.

The majority of the enclosed plots represent data obtained with the Mark III Mod 3 TPA, utilizing two different inlet systems. The first system incorporated a straight inlet pipe (Figure 1); data for this system was obtained from Test Series 1.2-04-NXP, 1.2-06-NNP, and 1.2-08-NNP. Series 1.2-04-NXP and 1.2-06-NNP differed from Series 1.2-08-NNP by the method of turbine drive--cold-gas (ambient gaseous

II, Discussion (cont.)

hydrogen, GH_2) drive versus hot-gas (600 to 800°F products of LH_2 and LO_2 combustion) drive, respectively (see Figures 2 and 3 for test area setup). The second inlet system utilized a centerbody inlet (alternate 1) TSOV tank and tank shutoff valve (TSOV). This configuration was used in order to more closely approximate conditions at the bottom of the engine tank. Data from Test Series 1.2-09-NNP was obtained with the centerbody configuration (Figure 4) using cold-gas (ambient GH_2) turbine drive (see Appendix C for impeller and housing test history).

Nondimensional relations were utilized. In the process of applying the laws of similitude, it was revealed that the pump performance parameters would not completely normalize over the entire speed range. However, a range of 15K to 24K rpm was sufficient for a meaningful analysis of pump performance.

The data presented in Figures 5 thru 22 are representative of pump performance during tests with both the straight and the centerbody (alternate 1) inlet system.

It is to be noted that the data points given represent the "steady-state" portions of the run. For example, the run time between 47 and 69 sec during Test 1.2-06-NNP-002 (Figure 23) was considered to be at steady-state conditions. It is for this reason that these plots are more representative of steady-state performance than previously published curves.

Figures 5 to 14 represent head rise versus suction head ($\frac{\Delta H}{N^2}$ vs $\frac{H_{sv}}{N^2}$) as tabulated from all of the test series (see Appendix B for parameter description and methods of calculation). An examination of Figures 10, 11, and 12 reveals a 4% to 5% decrement in head between data obtained with the centerbody inlet and straight inlet line. This difference in performance is also evident where pump efficiency is plotted against suction head (η_p vs $\frac{H_{sv}}{N^2}$). With respect to Figures 18, 19 and 20, it should be noted that the measured suction pressures were taken

II, Disucssion (cont.)

at different locations for each inlet system: at a station 14.3 in . from the pump interface for the straight inlet, and at 75 in. from the interface for the alternate 1 centerbody inlet. Measurement points were selected that were compatible with smooth flow. A direct comparison of data for the same NPSH, therefore, does not properly account for inlet pipe friction flow losses and heat transfer losses. A comparison of Figures 24 and 25 ($\frac{\Delta H}{N^2}$ vs $\frac{Q}{N}$) and Figures 26 and 27 (η_p vs $\frac{Q}{N}$), in addition to the curves mentioned previously, reveals this difference in performance.

It should be noted that the solid lines indicate performance substantiated by test results, and the dotted lines indicate predicted performance (except where $\frac{H_{sv}}{N^2} = 0.2 \times 10^{-6} \frac{ft}{rpm^2}$, straight inlet, where the point of drop off at $\frac{Q}{N} = 0.435$ has been substantiated).

Figure 28 ($\frac{NPSH}{N^2}$ vs $\frac{Q}{N}$) demonstrates the greater operating limits of the pump when the straight inlet is used instead of the prototype inlet line. Figures 30 and 31 reveal the shift of the stall limit with a change in speed. The cross-sectional view (Figure 29) of the housing used during Test Series 1.2-09-NNP shows that this shift in stall could not have been caused by a faulty housing. In determining the stall limits, stall was defined as that time when a sharp decrease in head rise resulted as either Q/N was decreased, N was increased, or $\frac{NPSH}{N^2}$ was decreased without any other condition parameter change. The stall limits were determined from computer printout and oscillograph data.

The pump performance maps, Figures 32 to 36, demonstrate the capabilities of the pump with the straight inlet at 20,000, 22,000, and 24,000 rpm at $\frac{H_{sv}}{N^2}$ (net positive suction head) values of 2×10^{-6}, 1×10^{-6}, 0.5×10^{-6}, 0.2×10^{-6} and $0.15 \times 10^{-6} \frac{ft}{rpm^2}$. The predicted performance at 26,000 rpm is also shown; the data represents pump performance with the long-inducer impeller (Mark III

II, Discussion (cont.)

Mod 3 impeller, Figure 37). These plots are based on the $\frac{\Delta H}{N^2}$ vs $\frac{Q}{N}$ and η_p vs $\frac{Q}{N}$ plots and are the result of cross plotting, not the actual plotting of data points.

The values of NPSP noted on the maps were determined by converting the net positive suction head to pressure. This was done by using the inlet (suction) specific weight. To determine the weight rate of flow propellant, it was necessary to determine the relationship between suction and discharge specific weight (flowmeter) at discharge). Figure 38 reveals this relationship. It is of interest to note that the fluid density at the pump discharge was greater than the fluid density at the pump suction during the tests with the straight inlet and that the discharge density was less than the density at the TSOV tank during tests with the alternate 1, gimbal inlet (Figure 39).

Figures 40 to 43 depict pump performance with the alternate 1 centerbody inlet. It should be noted that the test data for the alternate 1 centerbody inlet was limited to Q/N values in the range 0.25 to 0.32. The greater part of the performance presented in these curves was based on the assumption that the performance with the straight inlet would differ from the performance with the alternate 1 gimbal inlet by a constant, at a given $\frac{H_{sv}}{N^2}$. This assumption was based on a comparison of the data obtained, which is shown on Figure 44. The assumption, though not completely substantiated, appears to be quite valid at high suction heads; however, the validity breaks down somewhat at low flow rates and low suction heads.

The stall limits of the pump are noted on the map. These were obtained from the plots of rpm vs Q/N and $\frac{NPSH}{N^2}$ vs $\frac{Q}{N}$ (Figures 28 and 31).

Figures 45, 46 and 47 represent pump performance with the straight inlet at NPSP's of 2, 5, and 10 psi, respectively, at various speeds. From these curves it was possible to present performance maps at constant NPSP values, as shown in Figures 48, 49, and 50. Similar maps for the alternate 1 centerbody inlet are also presented (Figures 51, 52, and 53). These latter maps were also based on the assumption that pump performance with the straight inlet differs by some constant from performance with the alternate 1 centerbody inlet, at a given net positive suction head.

Figures 54 and 55 illustrate the three-stage and two-stage turbine flow, respectively, versus the turbine pressure ratio ($\frac{W_t \sqrt{T_{Ti}}}{P_{TTi}}$ vs R_t), where R_t is the total turbine inlet pressure divided by the static turbine exhaust pressure (P_{TTi}/P_{Te}). Figures 56 and 57 show cross-sectional views of the two turbine configurations. As expected, the two-stage turbine (comparing cold-gas drive power levels) demonstrated a higher choked output than the three stage: $\frac{W \sqrt{T_{Ti}}}{P_{TTi}}$ of 0.475 for the two stage and 0.28 for the three stage at R_t's > 2; this, because the two stage is a modification of the three stage (three stage with first stage removed) and has a greater first nozzle throat area than the three stage (Figure 58).

Figures 59 and 60 show the two- and three-stage turbine total static efficiencies, respectively, versus speed parameter (η_t vs $N/\sqrt{T}$) for the cold gas (ambient H_2) drive test series at various total inlet to static-exhaust-pressure ratios. The efficiency presented (η_{t2}) depends upon shaft horsepower (SHP), which is calculated from pump efficiency based on enthalpy rise through the pump. It could be expected that the 1.2-09-NNP series would demonstrate a lower turbine efficiency than the 1.2-06-NNP series because of the number of turbine stages used; there were three stages during the 1.2-06-NNP series and only two during the 1.2-09-NNP series.

In Figure 63, where ΔP vs $\dot{W}$ is plotted, lines of constant, η_p, Q/N and P_{TTi}, are presented for an $\frac{H_{sv}}{N^2} = 0.2 \times 10^{-6}\ \frac{ft}{rpm^2}$, a T_{Ti} of 1140°R and R_t = 10. In order to get the lines of constant P_{TTi}, it was assumed that the actual energy output of the turbine ($\eta_t \dot{W} \Delta hi$) equals the input or available energy of the pump $\frac{\dot{W}_p \Delta P}{\eta_p}$. Because T_{Ti} was given as 1140°R, it was possible to go to

II, Discussion (cont.)

Curve 9675:64-076 (η_{t2} vs $\frac{N}{\sqrt{T_{Ti}}}$) and obtain values of η_t for various speeds. $\dot{W}_p$, ΔP, and η_p were obtained from Curve 9675:64-0344 (performance map of ΔP vs $\dot{W}$ with lines of constant η_p, Q/N, and N) for various Q/N's and speeds. $\frac{\dot{W}_p \Delta P}{\eta_p \eta_t}$, which equals $\dot{W}_t \Delta h_i$, was then tabulated.

The T-s diagram, 600°R to 5000°R for 20.4°R equilibrium hydrogen, was then employed to determine Δh_i. P_{TTi}'s (values of 600, 500, 400, 300, 200, and 150 psia) were chosen along an isotherm of 1140°R, and P_{Te}'s one-tenth the value of the P_{TTi}'s were taken along isentropes. Measuring the enthalpy for the various pressure drops yielded Δh_i.

Because $\dot{W}_t$ is related to P_{TTi} and T_{Ti} by the relationship $\frac{\dot{W}_t \sqrt{T_{Ti}}}{P_{TTi}}$ = 0.475 for an R_t = 10 (Figure 55), a plot of $\dot{W}_t \Delta h_i$ vs P_{TTi} was documented (Figure 61).

Given the tabulated values of $\frac{\dot{W}_p \Delta P}{\eta_p \eta_t}$ (equal to $\dot{W} \Delta h_i$), P_{TTi} was obtained from the $\dot{W}_t \Delta h_i$ vs P_{TTi} curve. P_{TTi} was then plotted against pump weight flow (Q/N converted to $\dot{W}_t$), Figure 62 lines of constant P_{TTi} were then drawn on the performance map (Figure 63).

The Mark III Mod 3 pump configuration was as follows:

Impeller discharge tip diameter	11.9 in.
Impeller inducer outside diameter	6.95 in.
Impeller discharge tip height	0.485 in.
Diffuser throat height	0.55 in.
Diffuser vane entrance (inside diameter)	12.68 in.
Inducer angle (to direction of rotation)	8.25°
Diffuser angle (to tangential)	9.25°

APPENDIX A

TEST RESULTS

FIGURE LIST

FIGURE LIST (cont.)

FIGURE LIST (cont.)

Straight Inlet Line

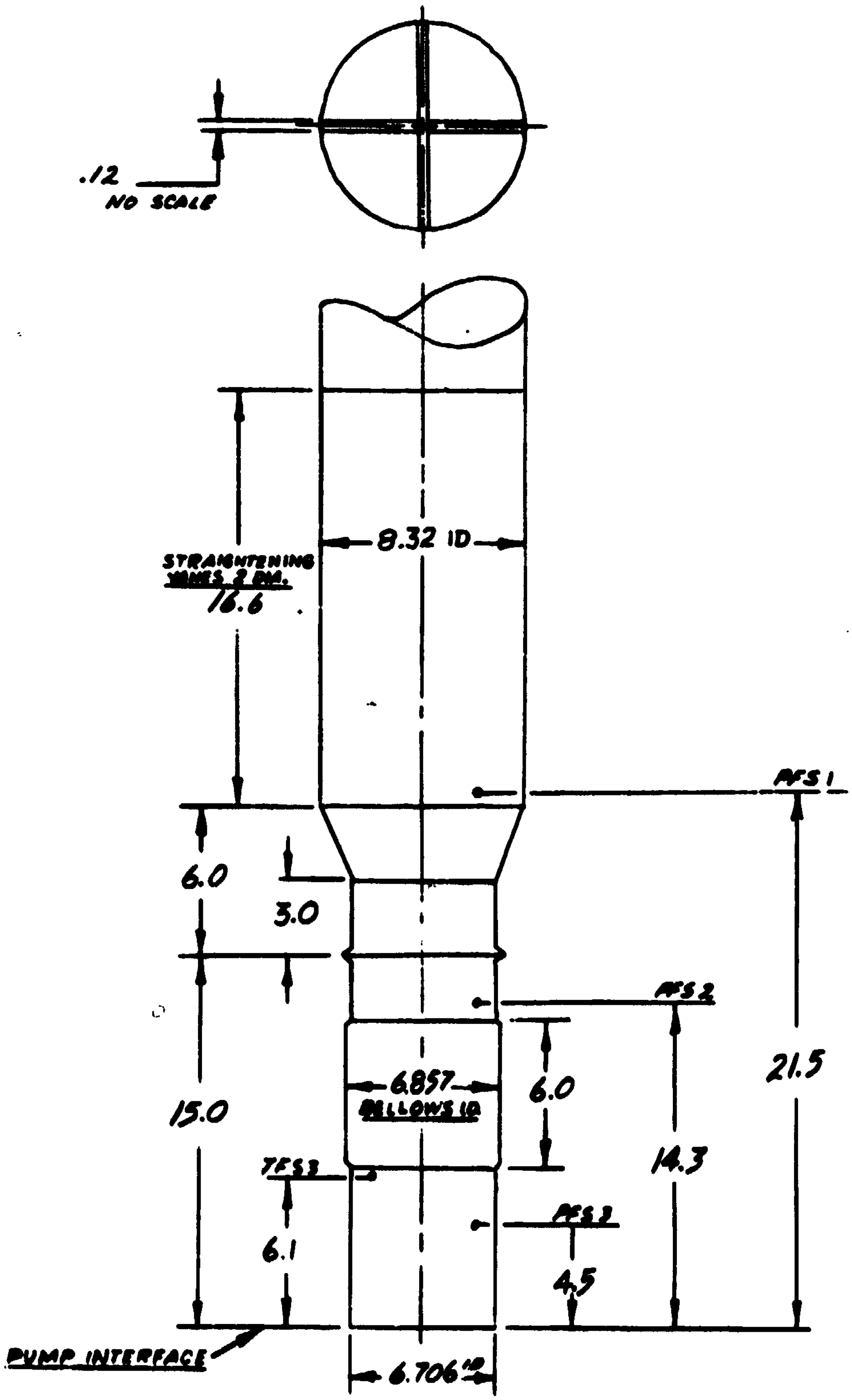


Figure 1

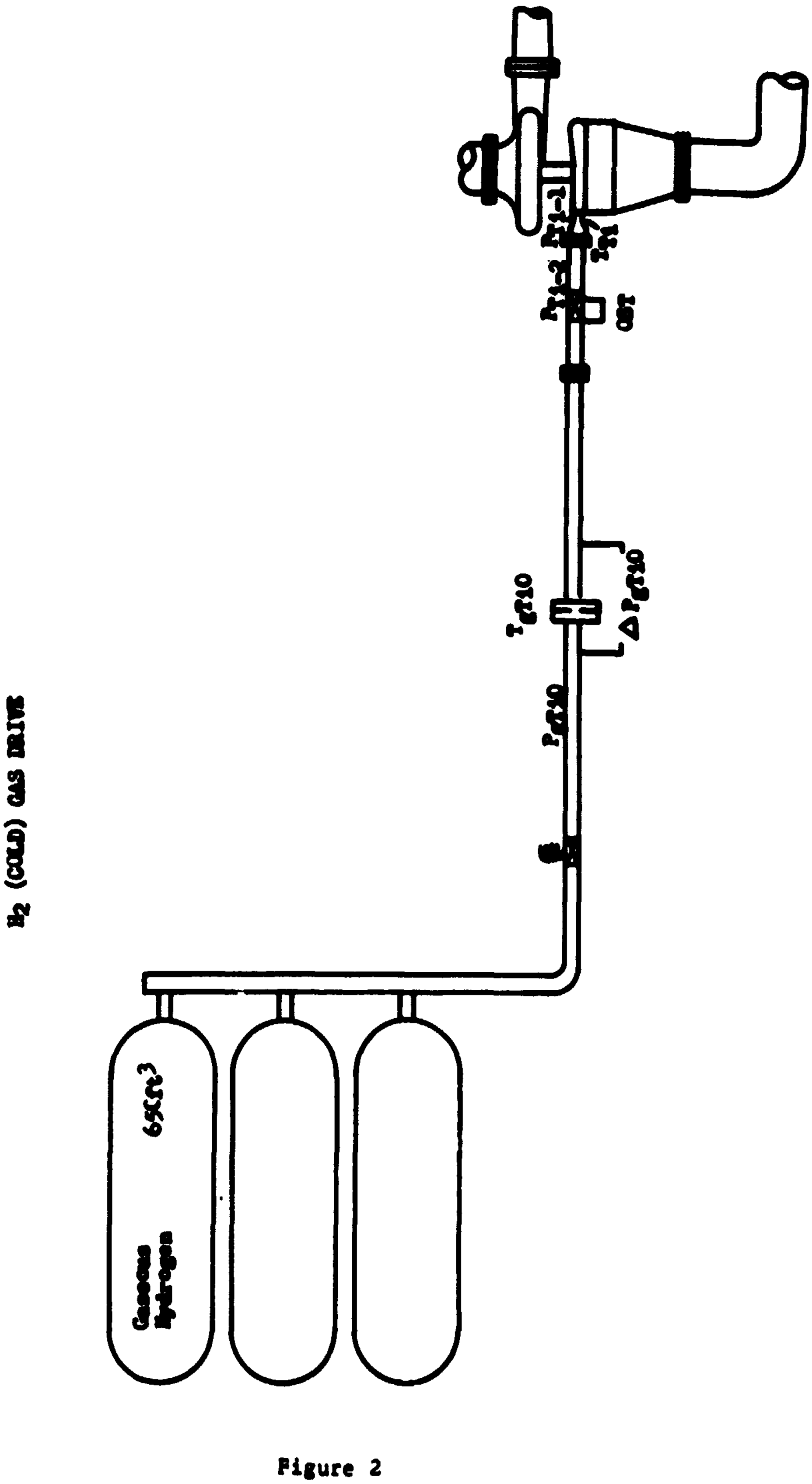


Figure 2

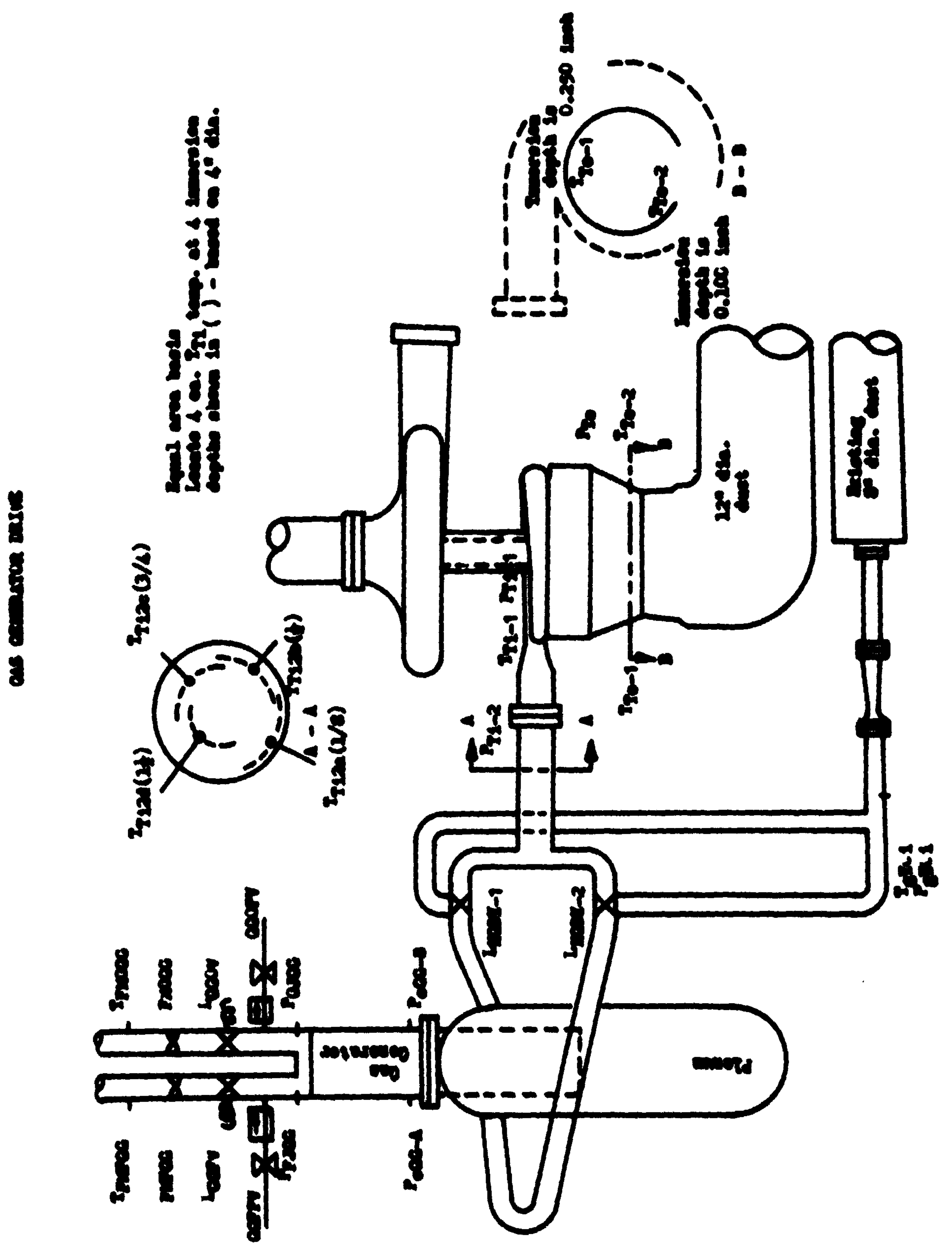
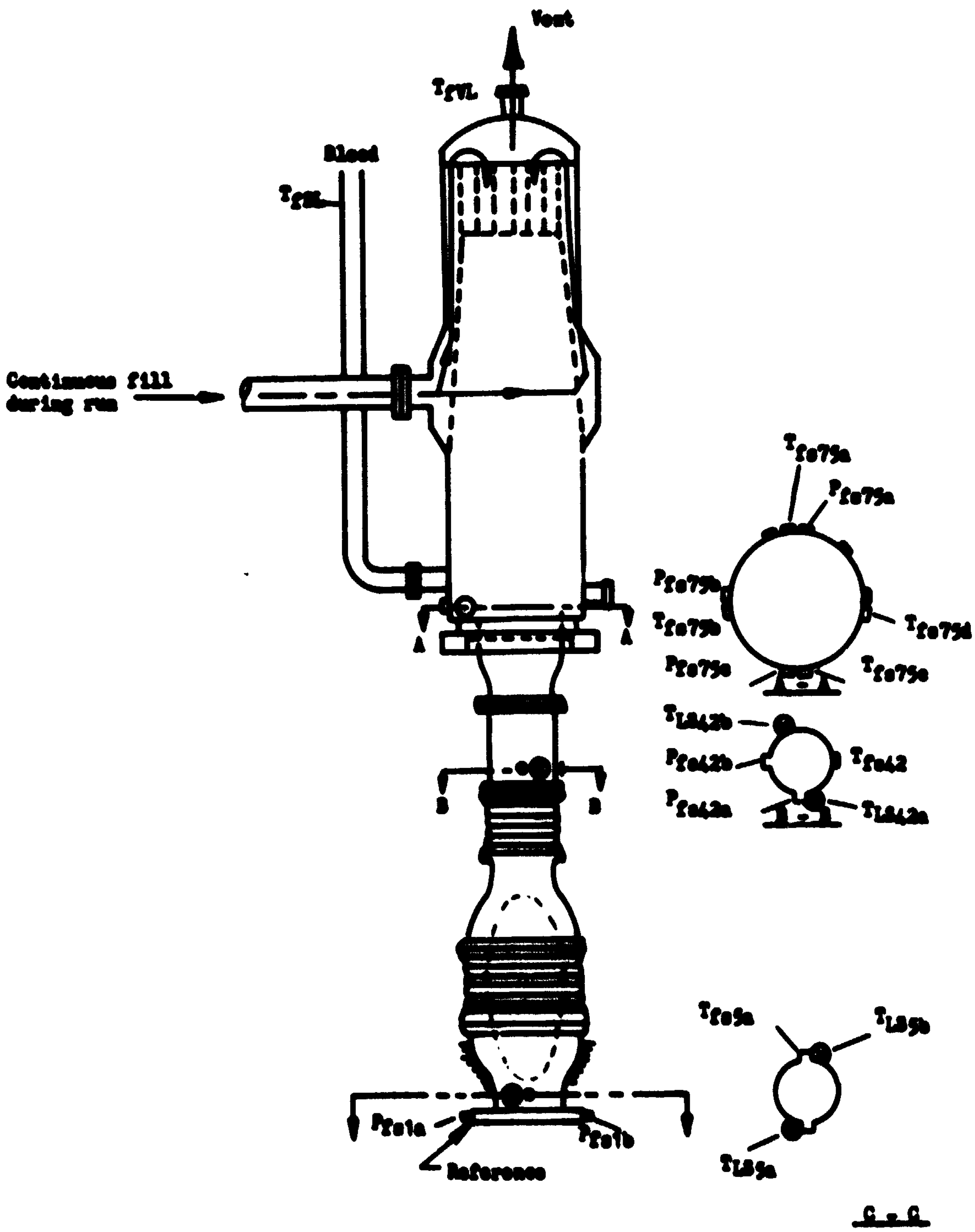


Figure 3

Report RN-S-0110, Appendix A

Alternate 1 Inlet



PUMP INLET SYSTEM
TEST STAND C-7

Skin Temp Probe

Figure 4

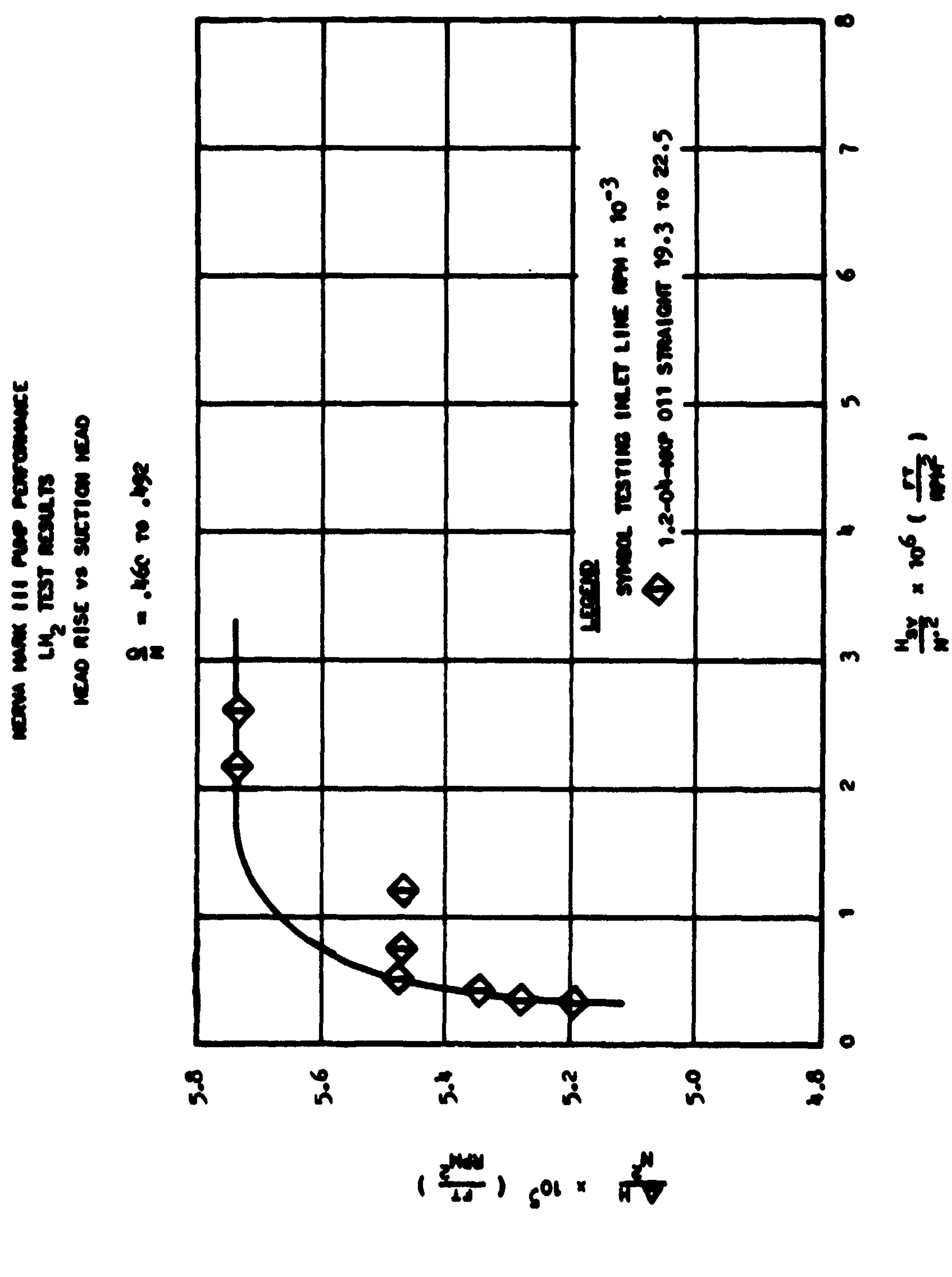

NERVA MARK III PUMP PERFORMANCE
LH_2 TEST RESULTS
HEAD RISE vs SUCTION HEAD
$\frac{Q}{N}$ = .466 TO .492
LEGEND
SYMBOL TESTING INLET LINE RPM x 10^{-3}
011 STRAIGHT 19.3 TO 22.5
5.8
5.6
5.4
5.2
5.0
4.8
0
1
2
3
4
5
6
7
8
$\frac{\Delta H}{N^2} \times 10^5$ ($\frac{FT}{RPM^2}$)
$\frac{H_{SV}}{N^2} \times 10^6$ ($\frac{FT}{RPM^2}$)

Figure 5

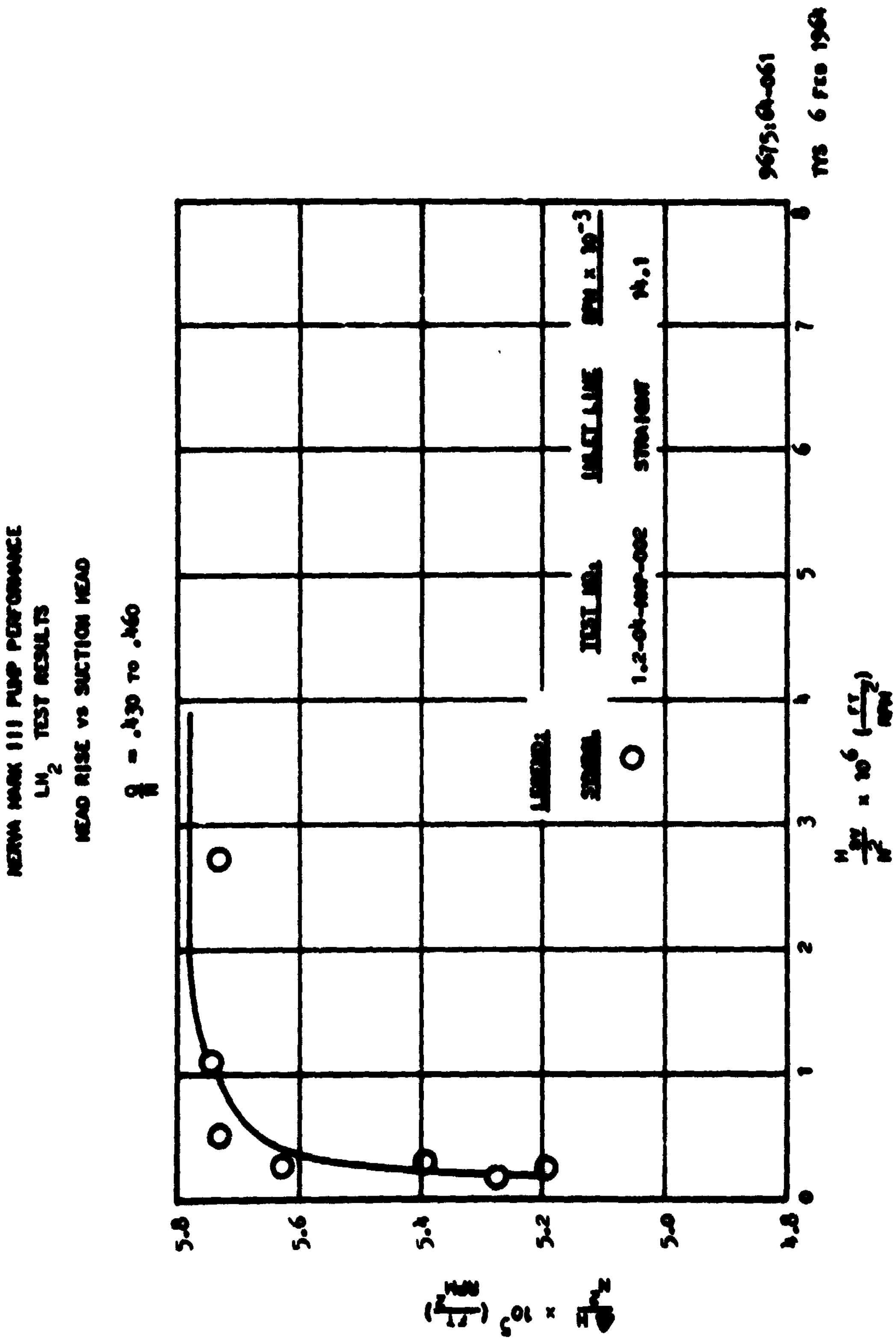

NERVA MARK III PUMP PERFORMANCE
LH2 TEST RESULTS
HEAD RISE vs SUCTION HEAD
9675:64-061
TYS 6 FEB 1964
LEGEND:
SYMBOL
TEST NO.
INLET LINE
STRAIGHT
0
1
2
3
4
5
6
7
8
4.8
5.0
5.2
5.4
5.6
5.8

Figure 6

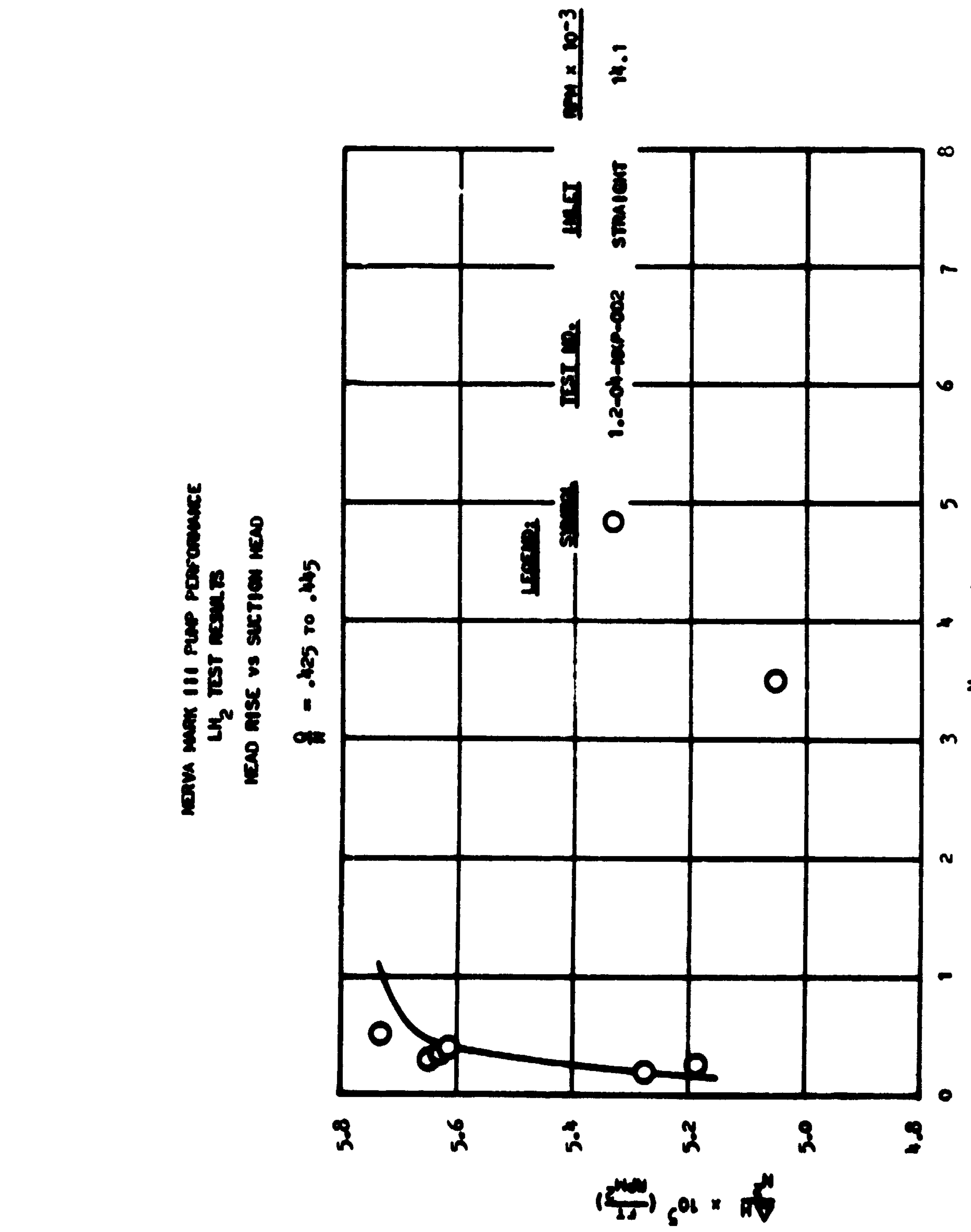

NERVA MARK III PUMP PERFORMANCE
LH2 TEST RESULTS
HEAD RISE vs SUCTION HEAD
Q/N = .425 TO .445
LEGEND:
SYMBOL
TEST NO.
INLET
RPM x 10-3
1.2-04-NKP-002
STRAIGHT
14.1
5.8
5.6
5.4
5.2
5.0
4.8
0
1
2
3
4
5
6
7
8

Figure 7

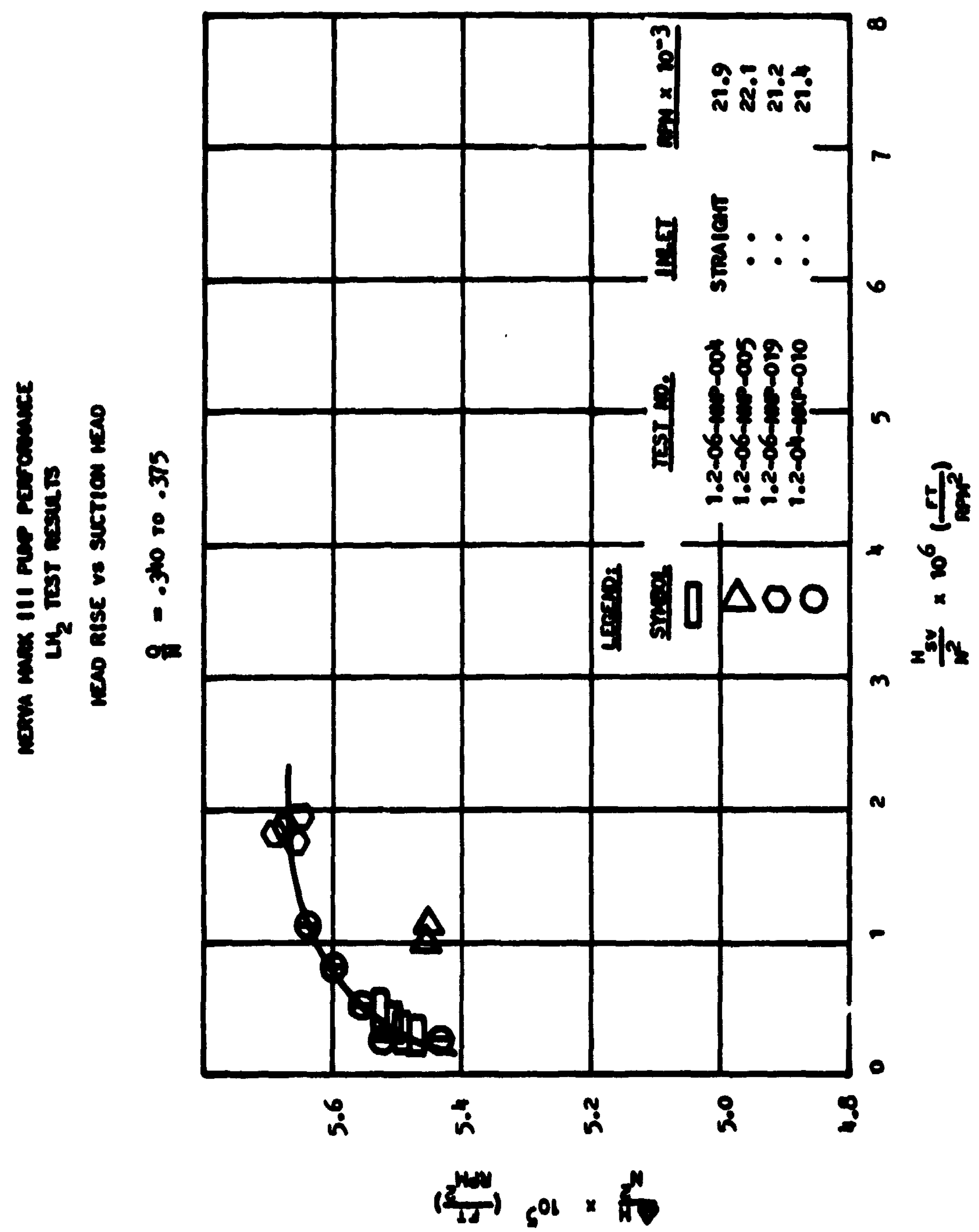

NERVA MARK III PUMP PERFORMANCE
LH_2 TEST RESULTS
HEAD RISE vs SUCTION HEAD
$\frac{Q}{N}$ = .340 TO .375
LEGEND:
SYMBOL
TEST NO.
INLET
RPM x 10^{-3}
STRAIGHT
21.9
22.1
21.2
21.4
$\frac{H_{sv}}{N^2} \times 10^6 \left(\frac{FT}{RPM^2}\right)$
$\frac{\Delta H}{N^2} \times 10^5 \left(\frac{FT}{RPM^2}\right)$
5.6
5.4
5.2
5.0
4.8
0
1
2
3
4
5
6
7
8

Figure 8

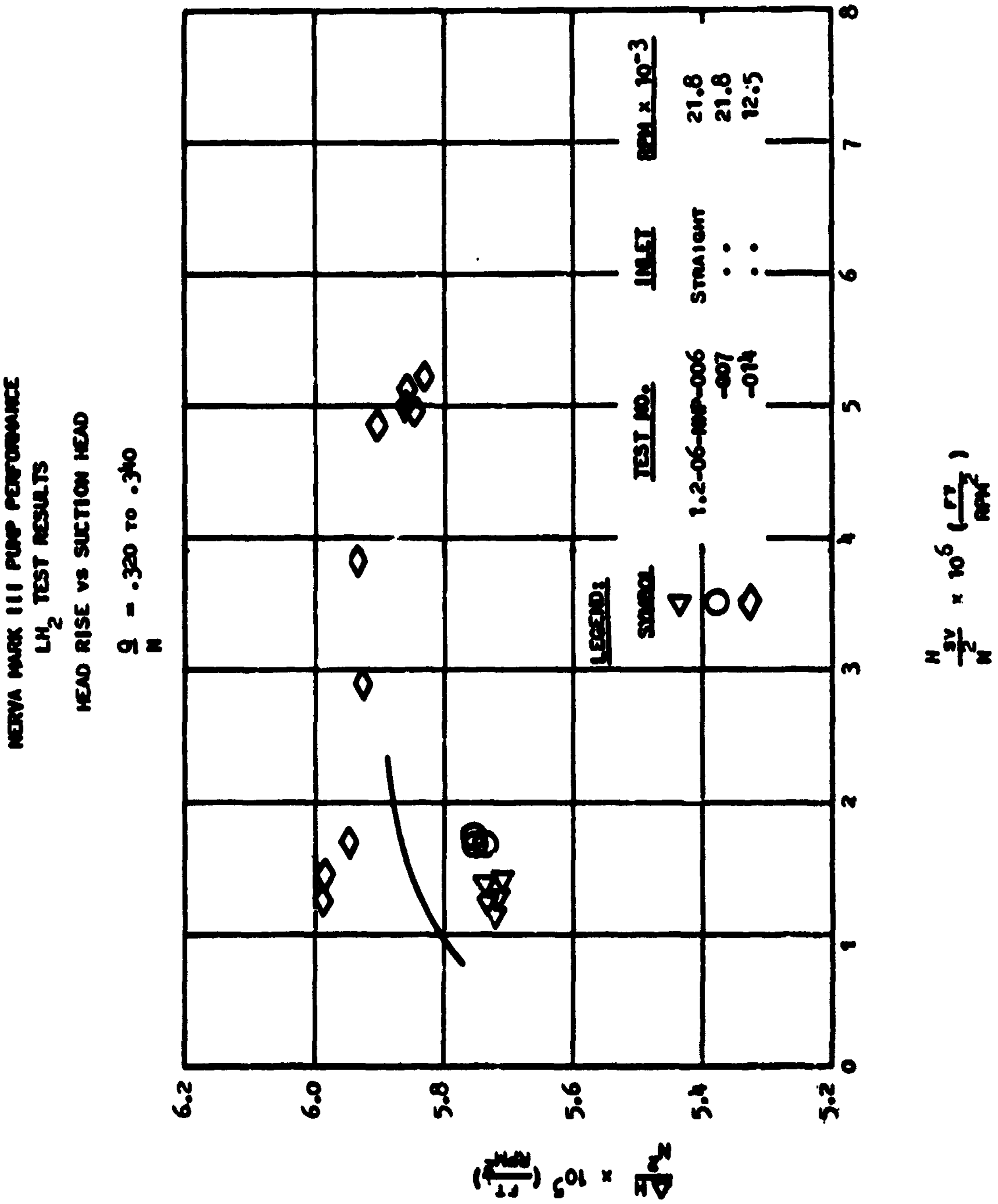
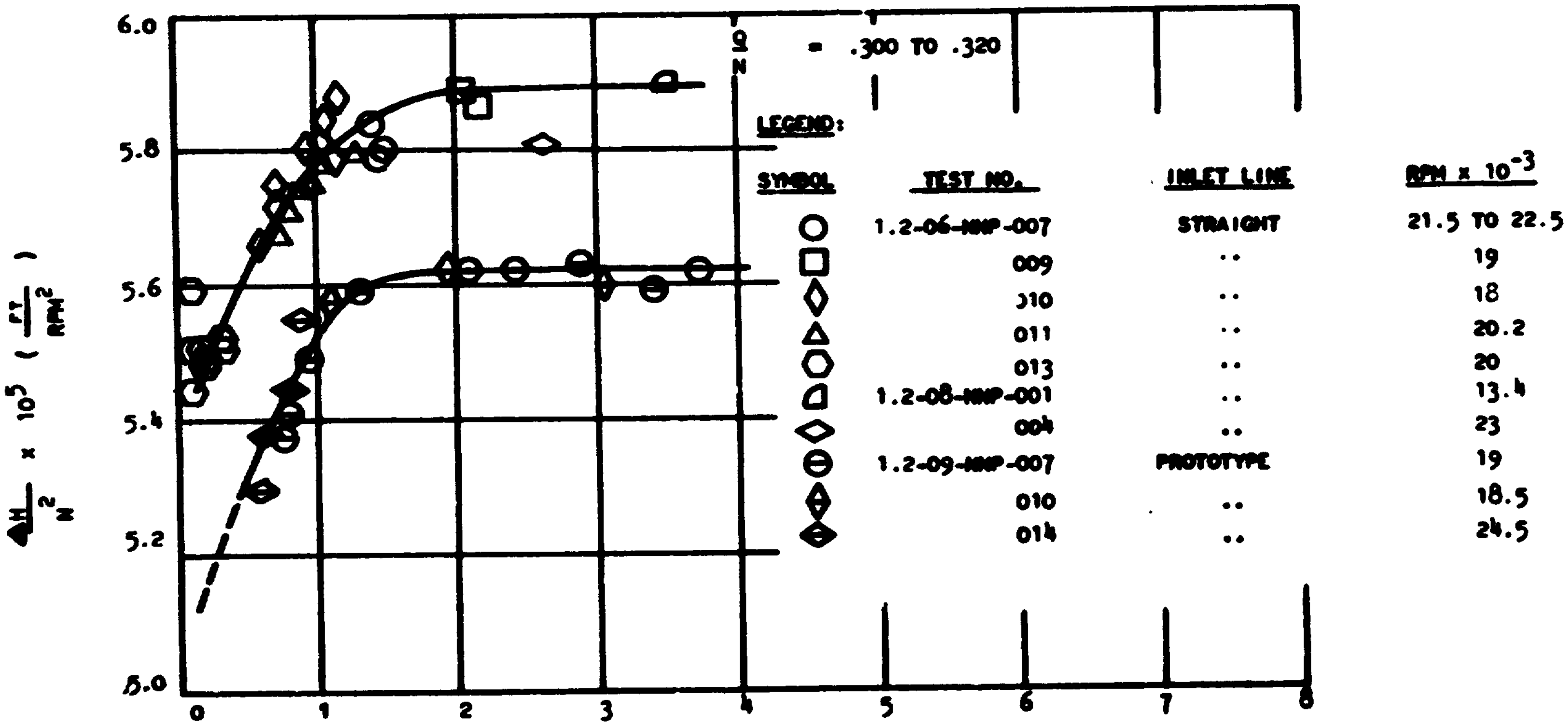

NERVA MARK III PUMP PERFORMANCE
LH2 TEST RESULTS
HEAD RISE vs SUCTION HEAD
Q/N = .320 TO .340
LEGEND:
SYMBOL
TEST NO.
INLET
RPM x 10-3
1.2-06-HRP-006
-007
-014
STRAIGHT
21.8
21.8
12.5
6.2
6.0
5.8
5.6
5.4
5.2
0
1
2
3
4
5
6
7
8

Figure 9

NERVA MARK III PUMP PERFORMANCE
LH_2 TEST RESULTS
HEAD RISE vs SUCTION HEAD



NOTE: H_{SV} FOR 1.2-06-NMP AND 1.2-08-NMP SERIES WAS MEASURED AT PUMP INLET; H_{SV} FOR 1.2-09-NMP SERIES WAS MEASURED AT THE TSOV INLET.

Figure 10

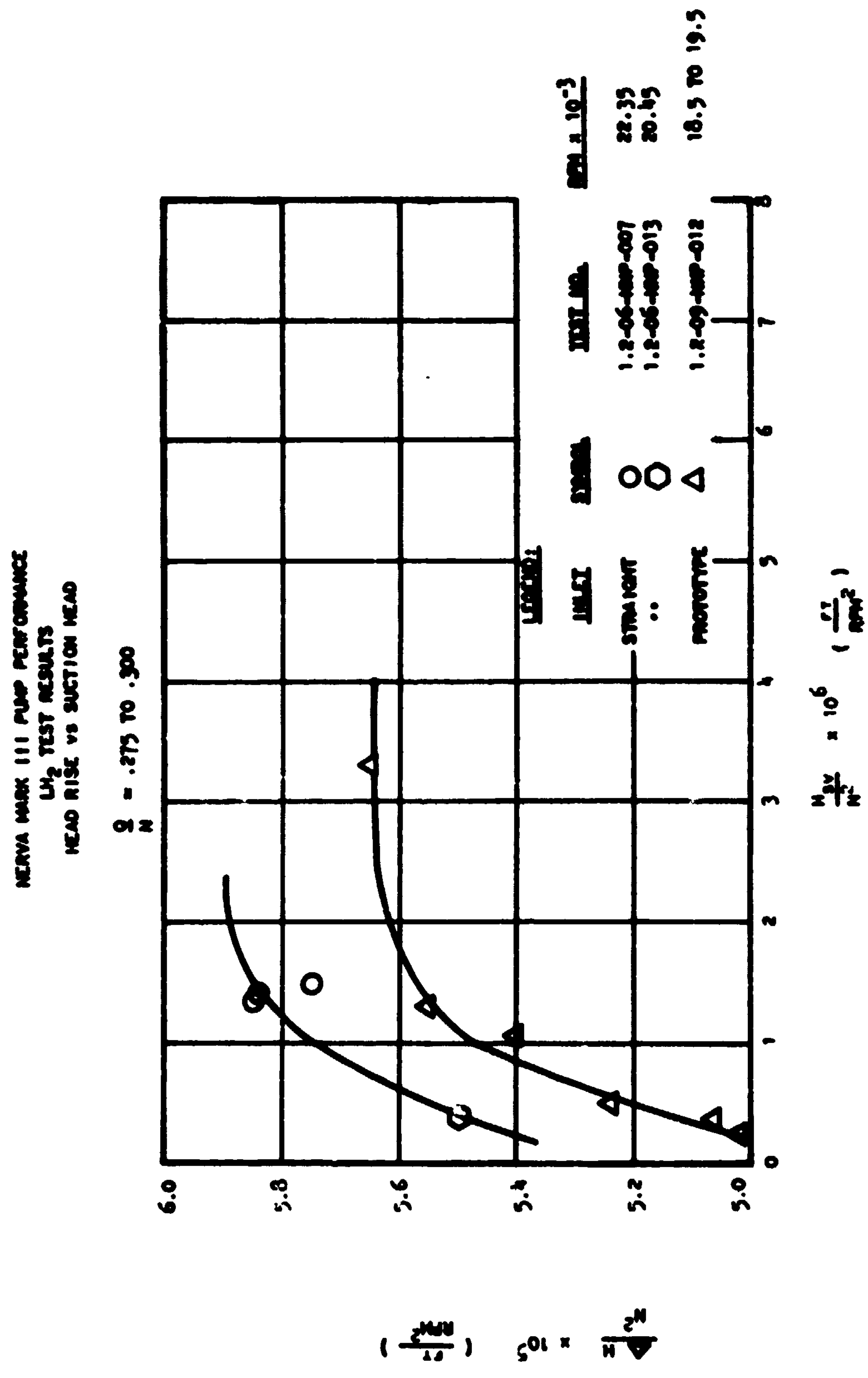

NERVA MARK III PUMP PERFORMANCE
LH_2 TEST RESULTS
HEAD RISE vs SUCTION HEAD
$\frac{Q}{N}$ = .275 TO .300
LEGEND:
INLET
SYMBOL
TEST NO.
RPM x 10^{-3}
STRAIGHT
"
PROTOTYPE
22.35
20.45
18.5 TO 19.5
6.0
5.8
5.6
5.4
5.2
5.0
0
1
2
3
4
5
6
7
8
$\frac{H_{SV}}{N^2} \times 10^6$ $\left(\frac{FT}{RPM^2}\right)$
$\frac{\Delta H}{N^2} \times 10^5$ $\left(\frac{FT}{RPM^2}\right)$

Figure 11

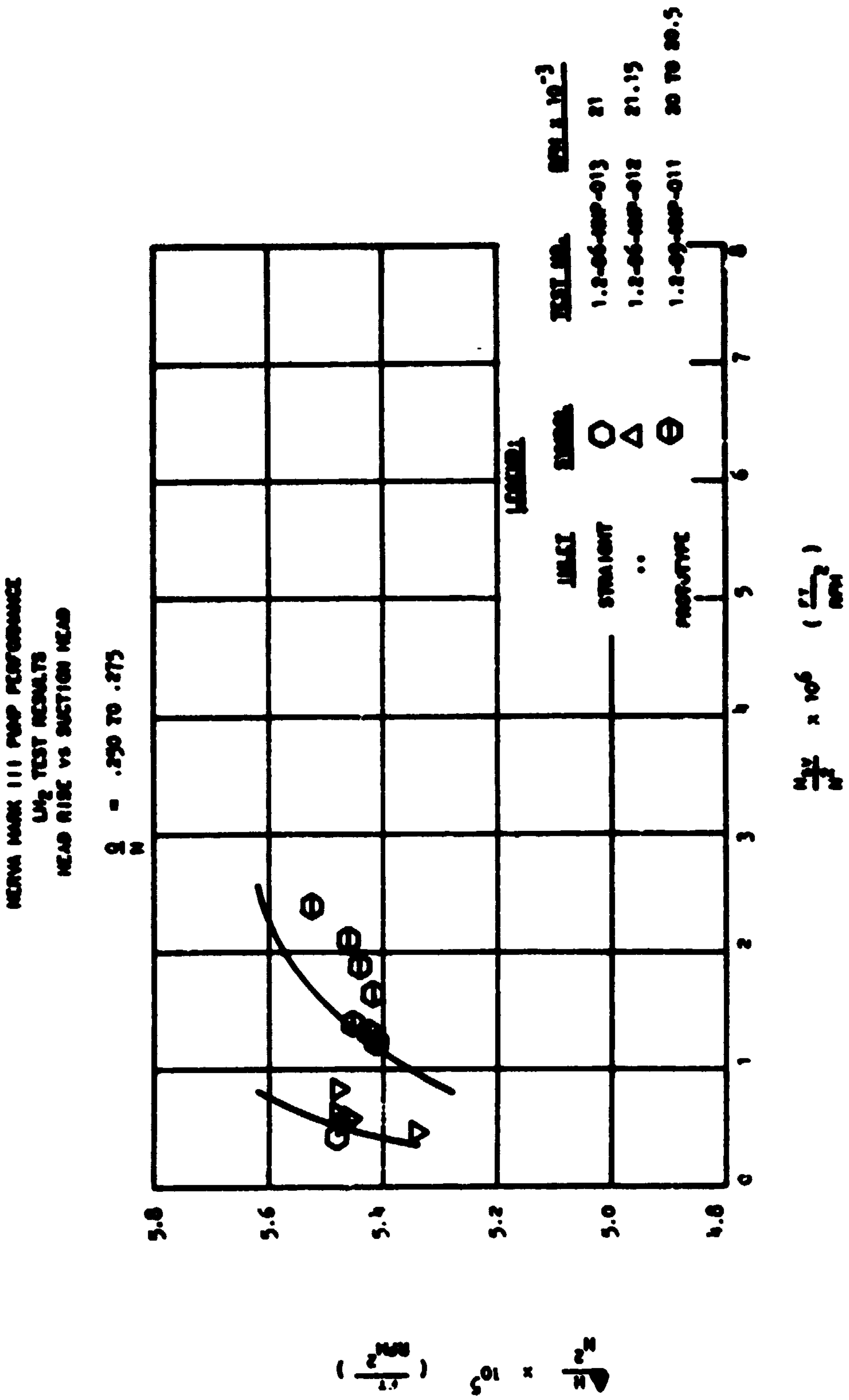

NERVA MARK III PUMP PERFORMANCE
LH_2 TEST RESULTS
HEAD RISE VS SUCTION HEAD
LEGEND:
INLET
STRAIGHT
PROTOTYPE
SYMBOL
TEST NO.
RPM x 10^{-3}
21
21.15
20 TO 20.5
5.8
5.6
5.4
5.2
5.0
4.8
0
1
2
3
4
5
6
7
8

Figure 12

NERVA MARK III PUMP PERFORMANCE
LH_2 TEST RESULTS
HEAD RISE vs SUCTION HEAD
$\frac{Q}{N}$ = .220 TO .250

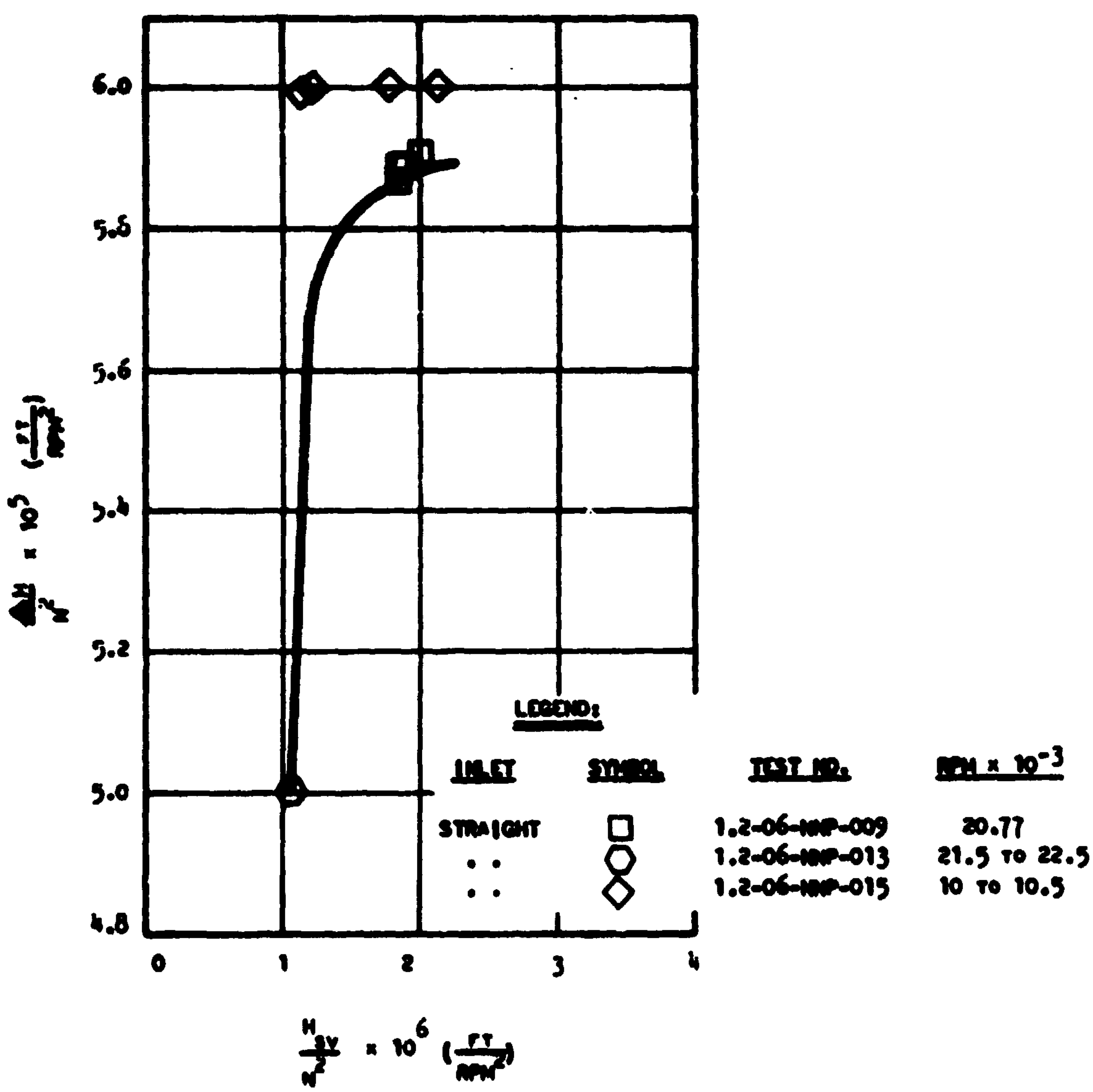


Figure 13

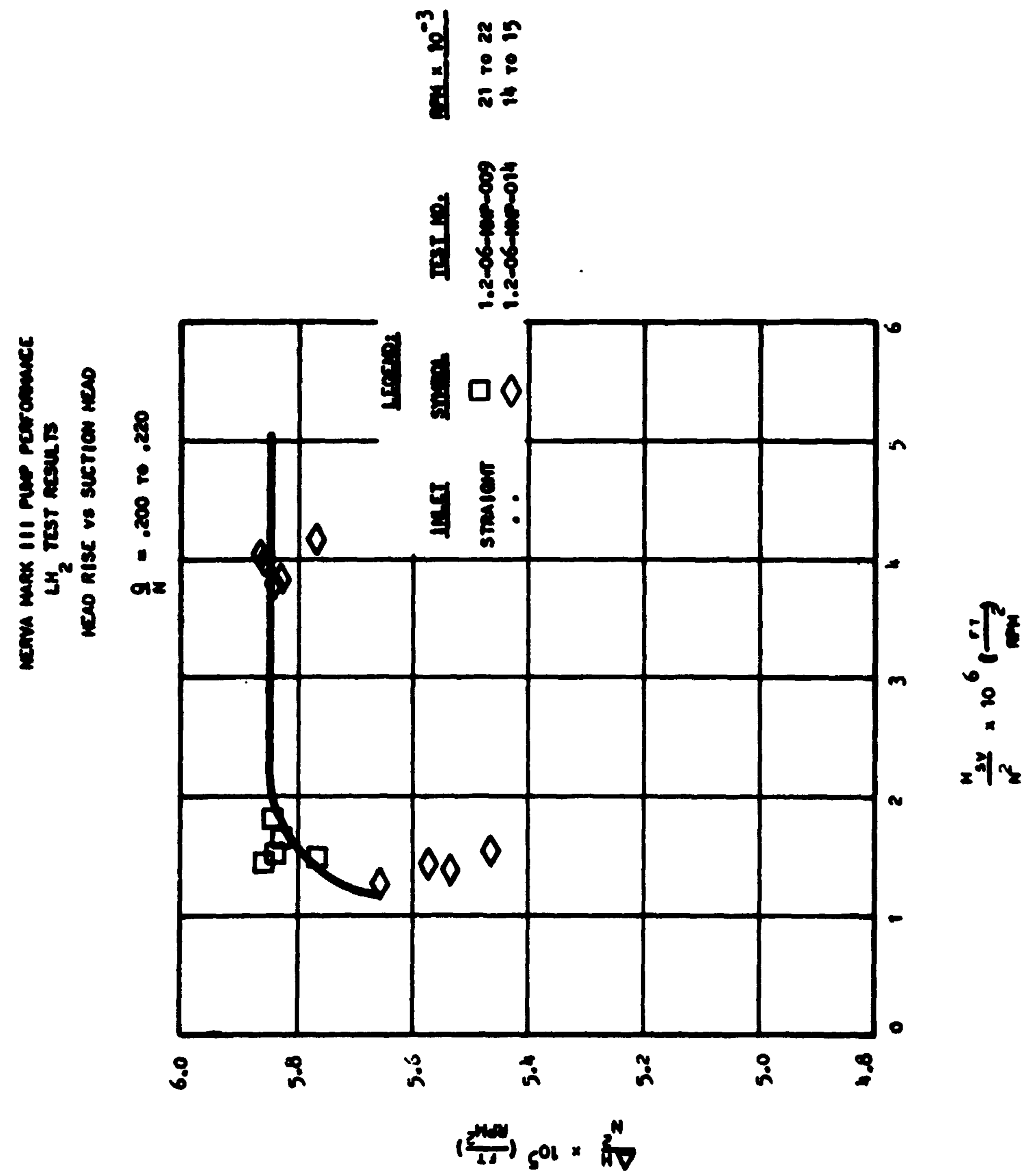

NERVA MARK III PUMP PERFORMANCE
LH_2 TEST RESULTS
HEAD RISE vs SUCTION HEAD
$\frac{Q}{N}$ = .200 TO .220
LEGEND:
INLET
STRAIGHT
SYMBOL
TEST NO.
RPM x 10^{-3}
21 TO 22
14 TO 15
$\frac{\Delta H}{N^2} \times 10^5 \left(\frac{FT}{RPM^2}\right)$
6.0
5.8
5.6
5.4
5.2
5.0
4.8
0
1
2
3
4
5
6
$\frac{H_{SV}}{N^2} \times 10^6 \left(\frac{FT}{RPM^2}\right)$

Figure 14

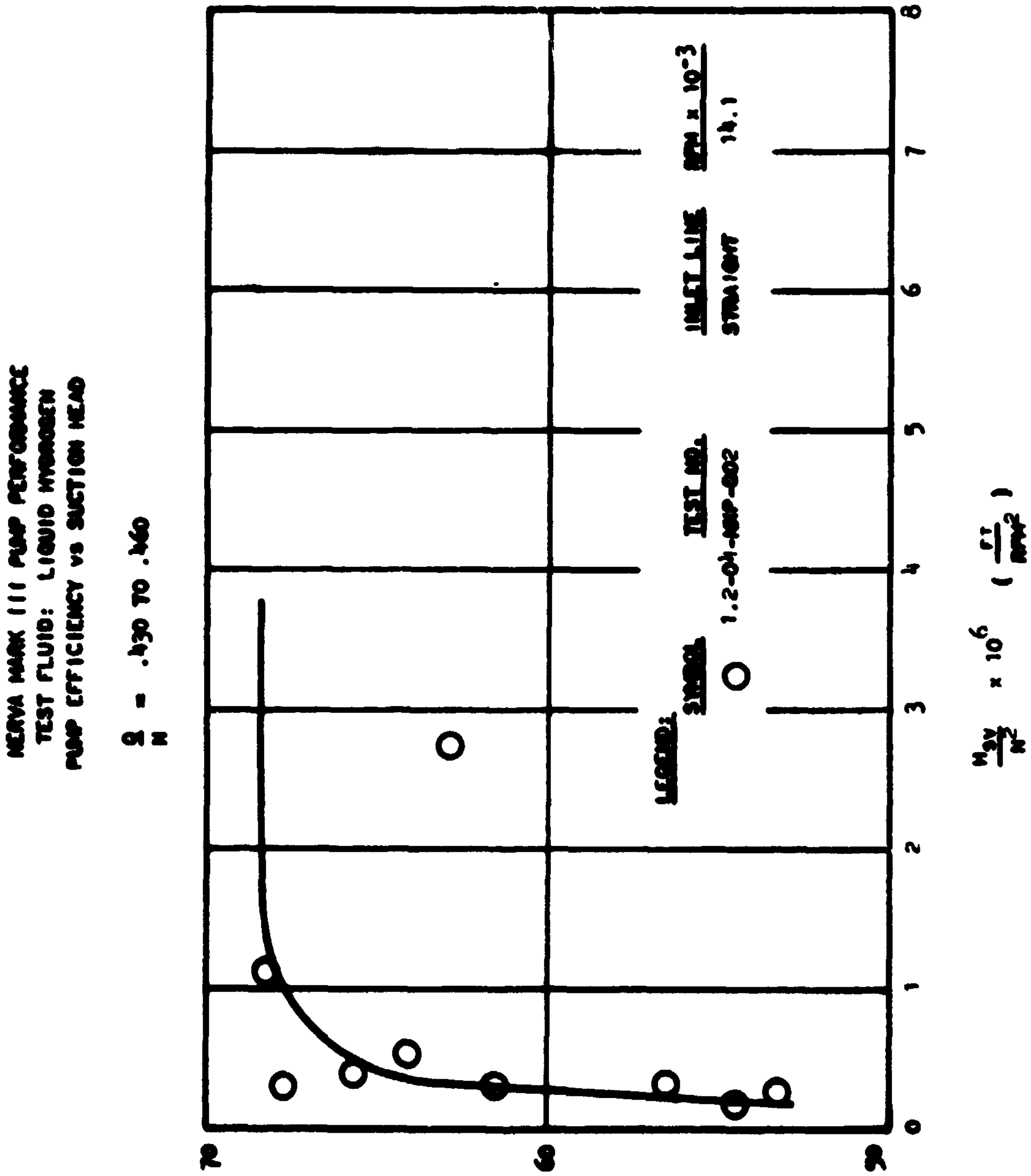

TEST FLUID: LIQUID HYDROGEN
PUMP EFFICIENCY vs SUCTION HEAD
LEGEND:
SYMBOL
TEST NO.
INLET LINE
STRAIGHT
RPM x 10^-3
14.1
0
1
2
3
4
5
6
7
8
70
80
90

Figure 15

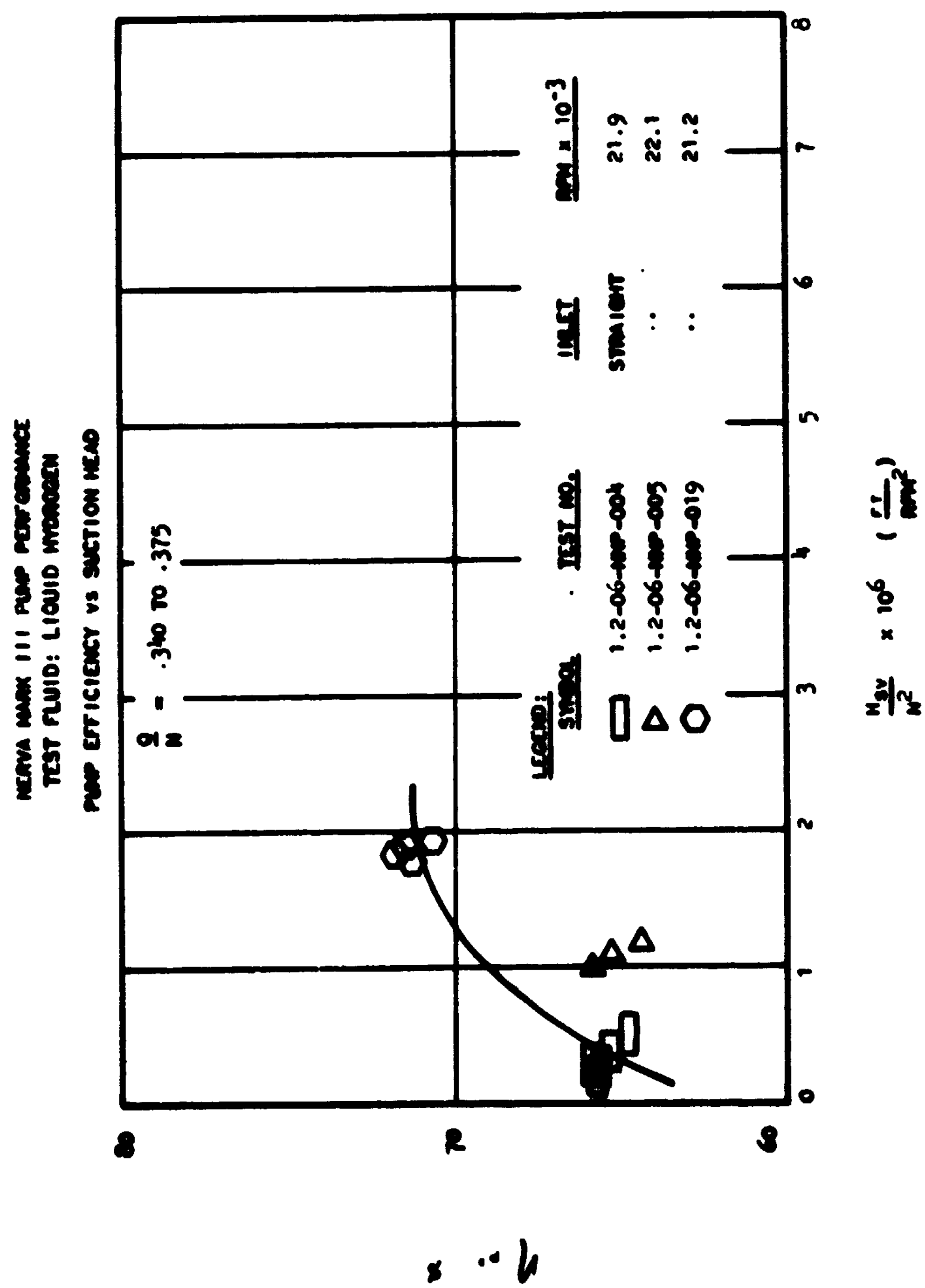

NERVA MARK III PUMP PERFORMANCE
TEST FLUID: LIQUID HYDROGEN
PUMP EFFICIENCY vs SUCTION HEAD
Q/N = .340 TO .375
LEGEND:
SYMBOL
TEST NO.
INLET
RPM x 10^-3
1.2-06-MBP-004
STRAIGHT
21.9
1.2-06-MBP-005
22.1
1.2-06-MBP-019
21.2
0
1
2
3
4
5
6
7
8
60
70
80
H_sv / N^2 x 10^6 (FT / RPM^2)
η, %

Figure 16

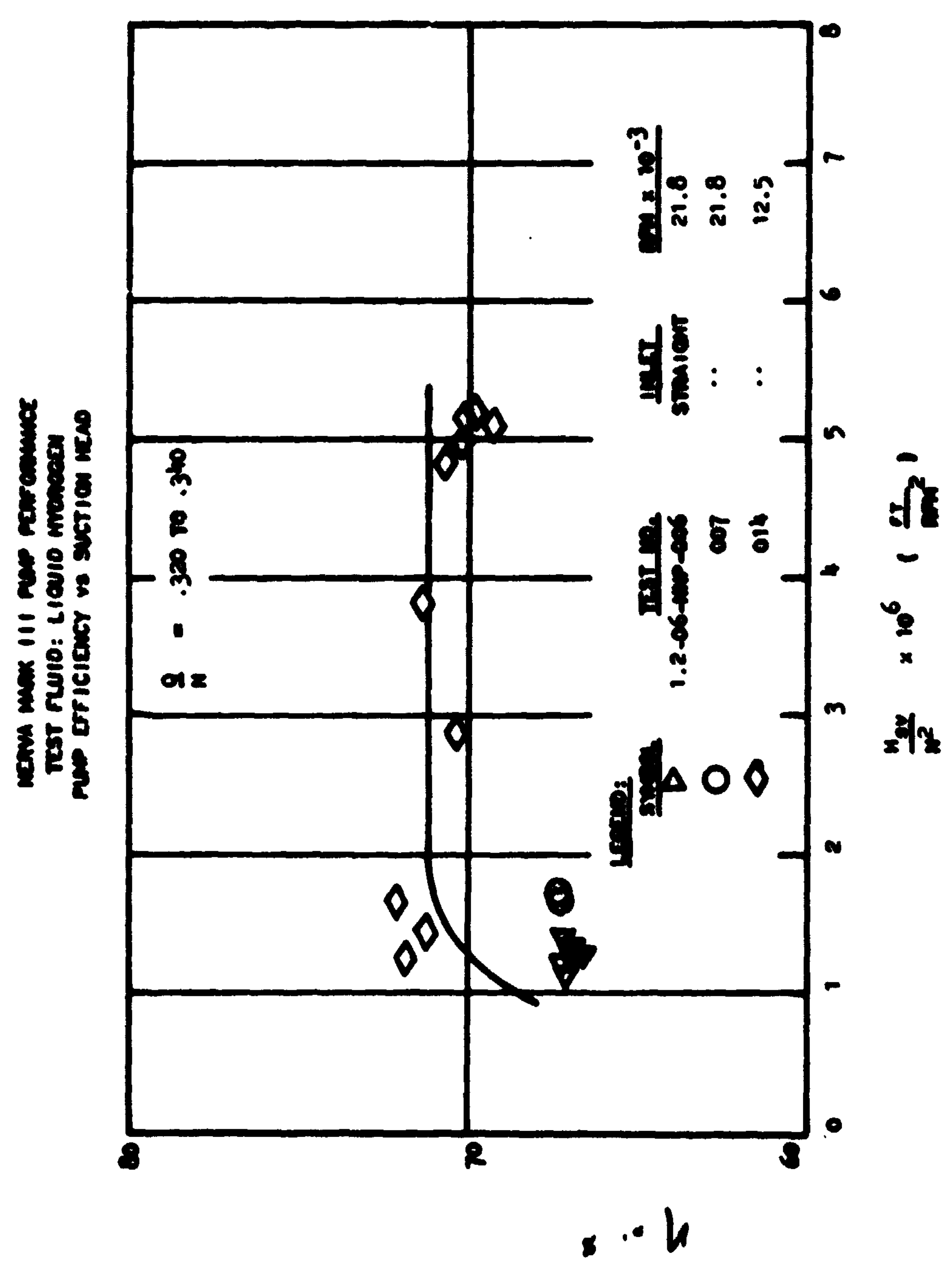

NERVA MARK III PUMP PERFORMANCE
TEST FLUID: LIQUID HYDROGEN
PUMP EFFICIENCY vs SUCTION HEAD
Q/N = .320 TO .340
LEGEND:
SYMBOL
TEST NO.
INLET
RPM x 10^-3
1.2-06-HHP-006
STRAIGHT
21.8
007
"
21.8
014
"
12.5
0
1
2
3
4
5
6
7
8
60
70
80
η_p %
H_SV/N^2 x 10^6 (FT/RPM^2)

Figure 17

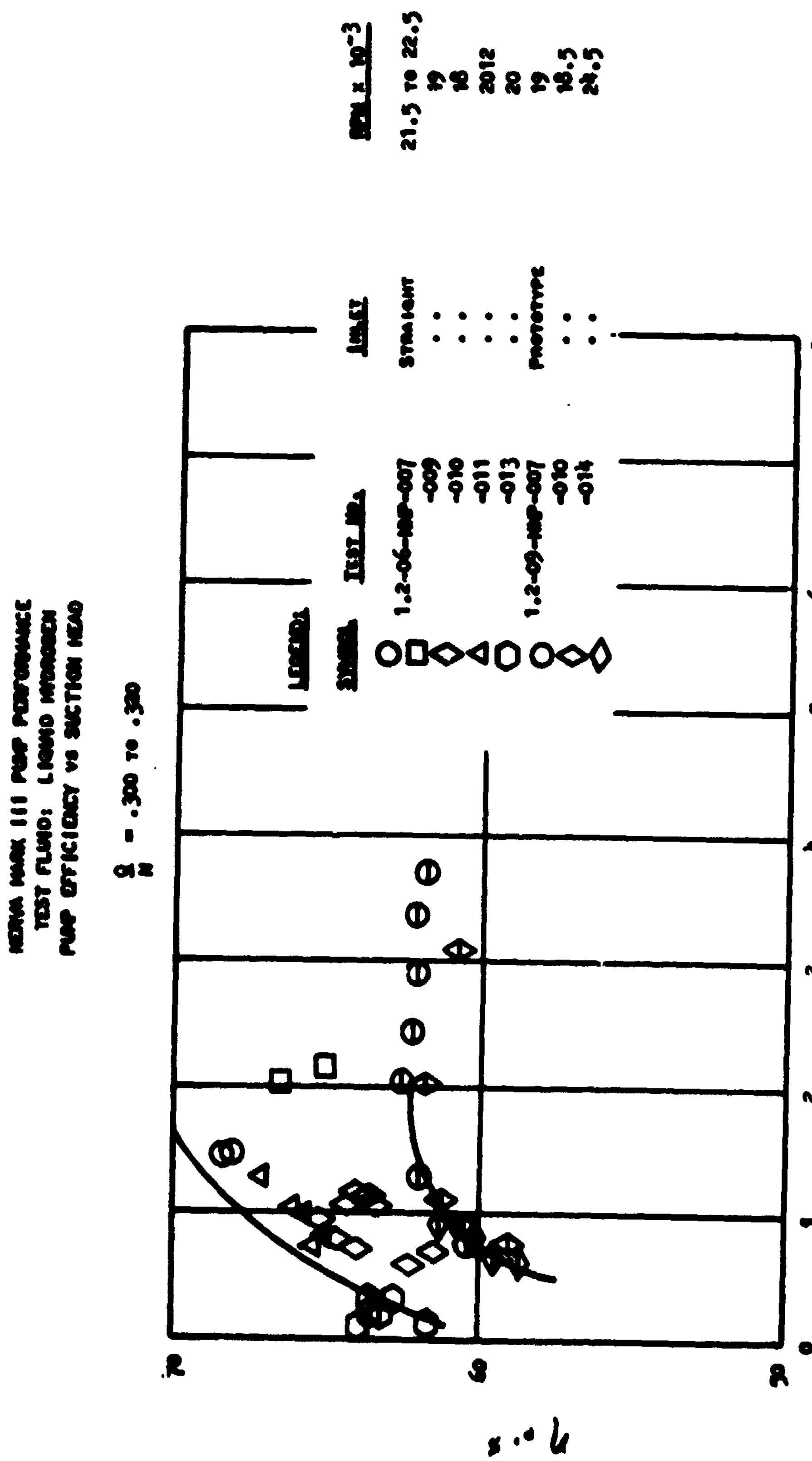

NERVA MARK III PUMP PERFORMANCE
TEST FLUID: LIQUID HYDROGEN
PUMP EFFICIENCY VS SUCTION HEAD
LEGEND:
SYMBOL
TEST NO.
1.2-06-HRP-007
-009
-010
-011
-013
1.2-09-HRP-007
-010
-014
INLET
STRAIGHT
PROTOTYPE
RPM x 10^-3
21.5 TO 22.5
0
1
2
3
4
5
6
7
8

Figure 18

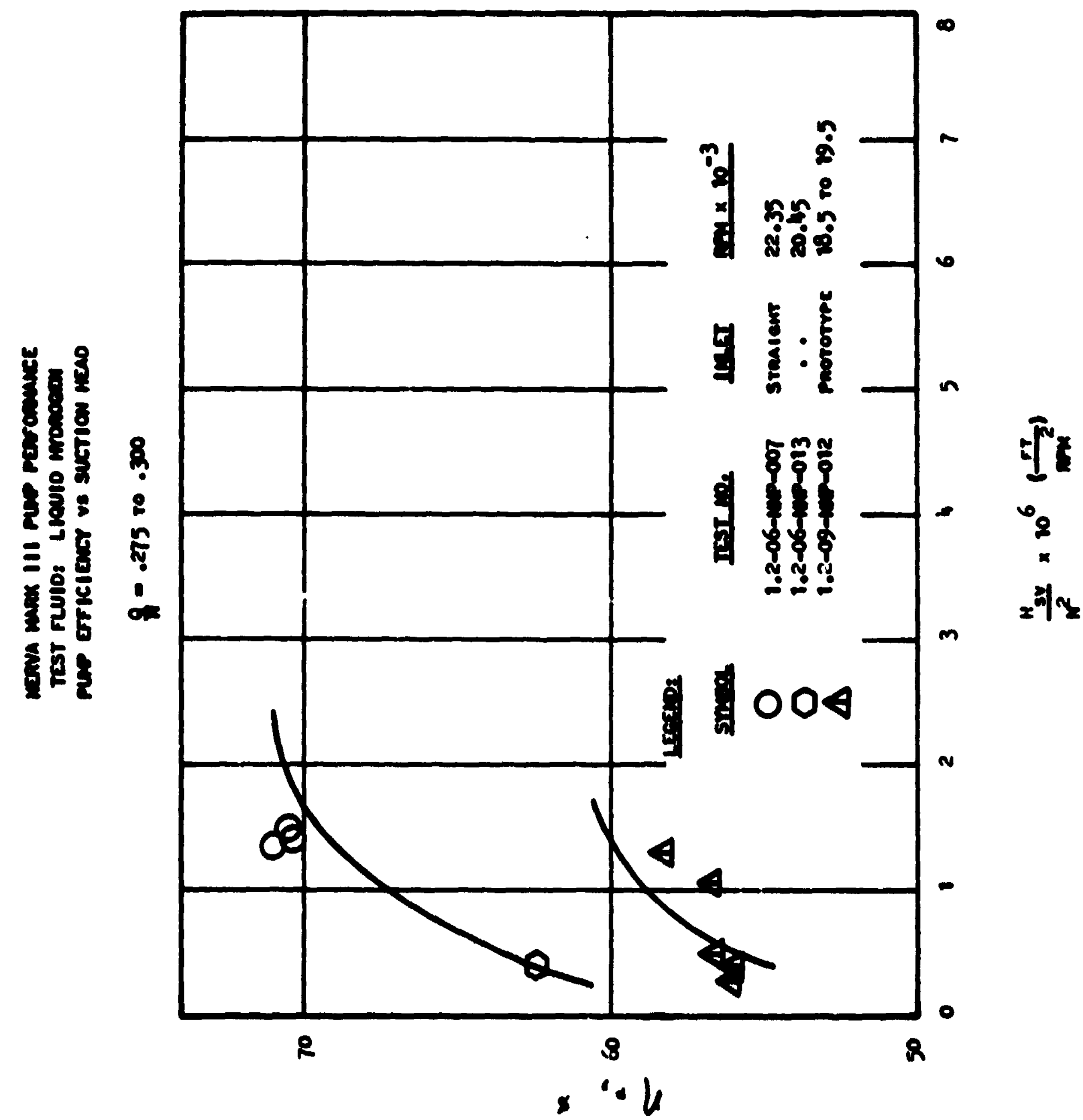


Figure 19

Short 1.1

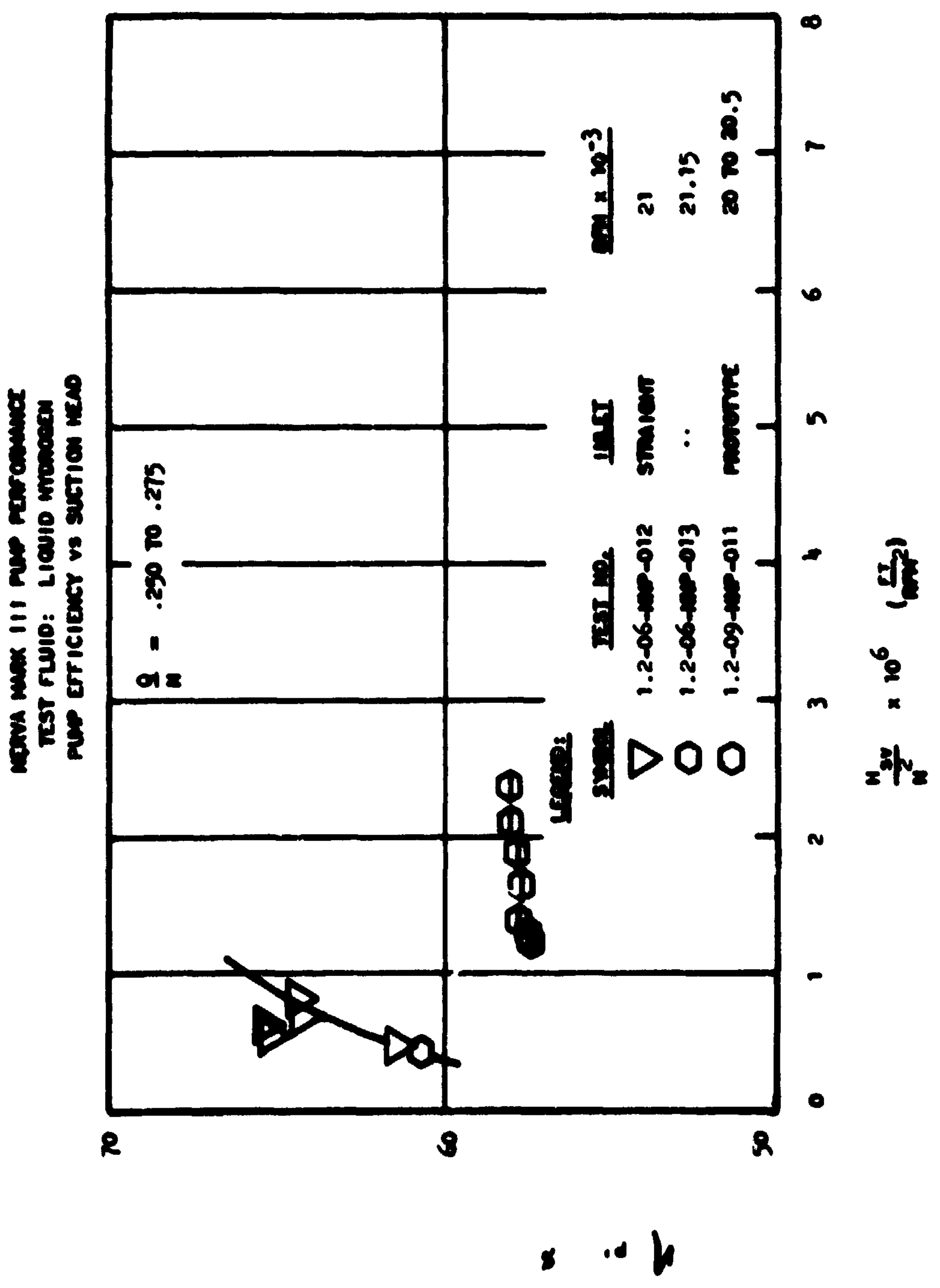

NERVA MARK III PUMP PERFORMANCE
TEST FLUID: LIQUID HYDROGEN
PUMP EFFICIENCY vs SUCTION HEAD
Q/N = .250 TO .275
LEGEND:
SYMBOL
TEST NO.
INLET
RPM x 10^-3
1.2-06-NHP-012
STRAIGHT
21
1.2-06-NHP-013
"
21.15
1.2-09-NHP-011
PROTOTYPE
20 TO 20.5
70
60
50
0
1
2
3
4
5
6
7
8
x 10^6

Figure 20

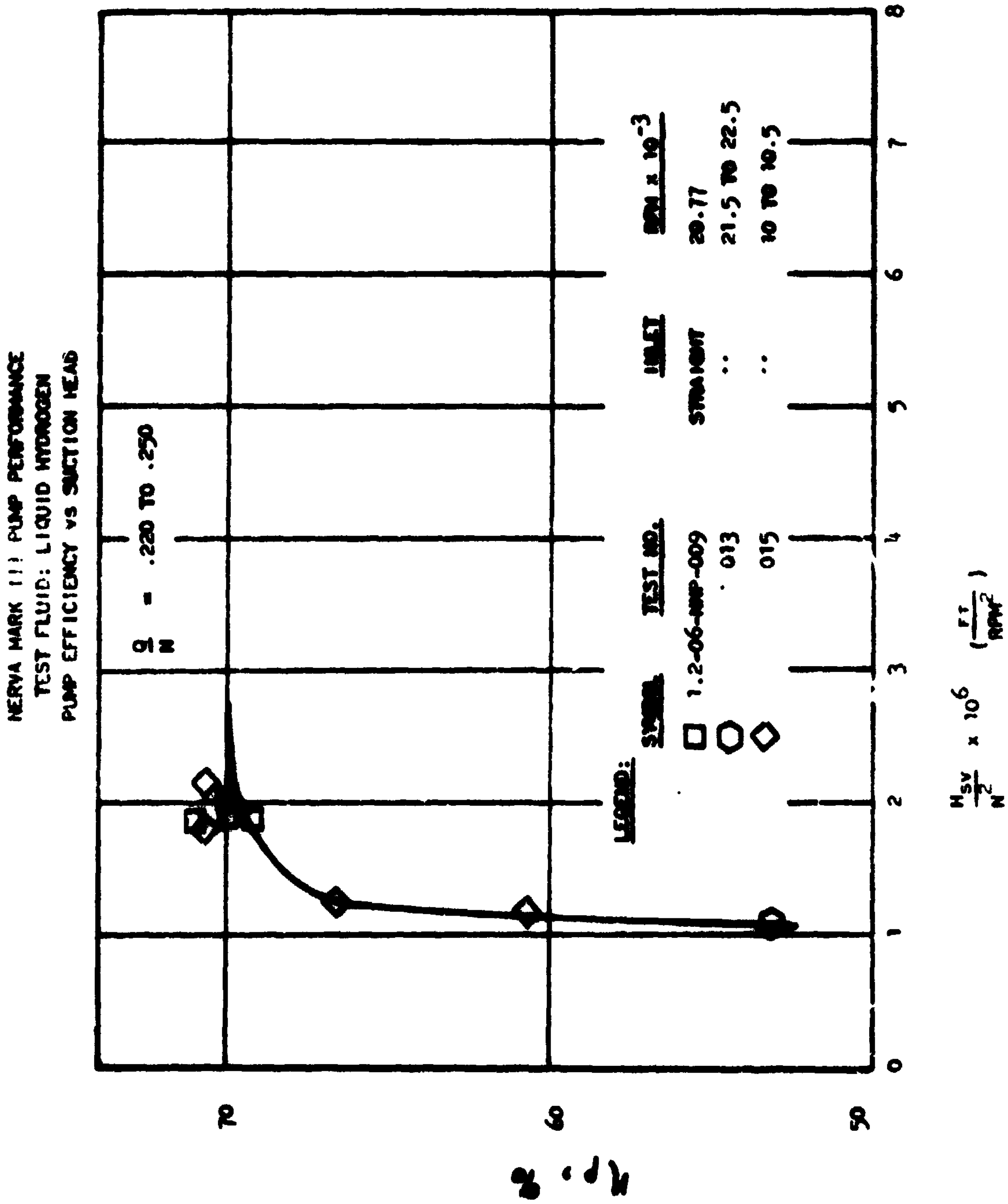

NERVA MARK III PUMP PERFORMANCE
TEST FLUID: LIQUID HYDROGEN
PUMP EFFICIENCY vs SUCTION HEAD
Q/N = .220 TO .250
LEGEND:
SYMBOL
TEST NO.
INLET
RPM x 10^-3
1.2-06-HMP-009
STRAIGHT
20.77
013
21.5 TO 22.5
015
10 TO 10.5
0
1
2
3
4
5
6
7
8
70
60
50
ηp, %
H_SV/N^2 x 10^6 (FT/RPM^2)

Figure 21

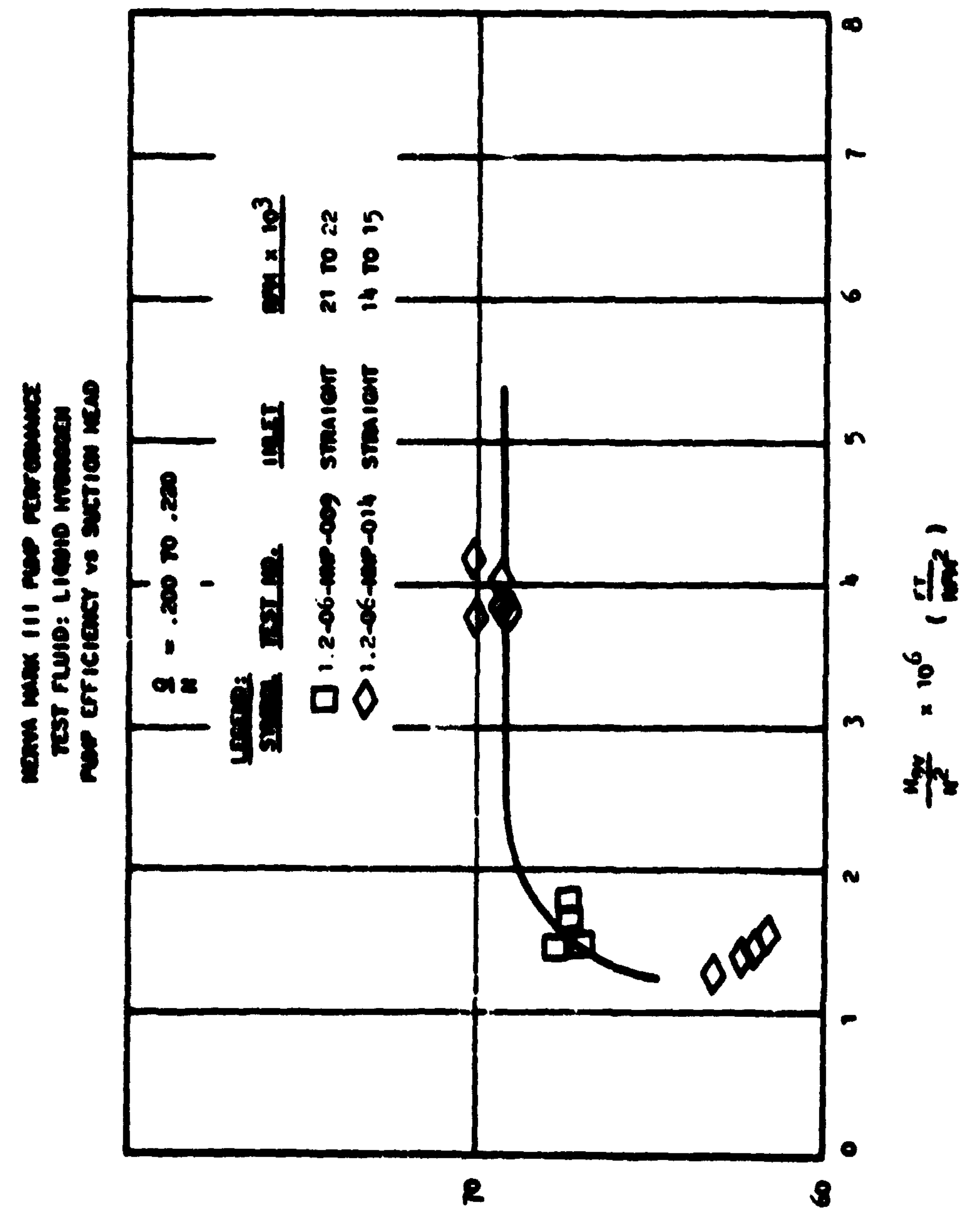

TEST FLUID: LIQUID HYDROGEN
PUMP EFFICIENCY vs SUCTION HEAD
= .200 TO .220
LEGEND:
TEST NO.
INLET
1.2-06-HRP-009 STRAIGHT 21 TO 22
1.2-06-HRP-014 STRAIGHT 14 TO 15
0 1 2 3 4 5 6 7 8
70
80

Figure 22

NERVA
MARK III TURBOPUMP
LH_2 PUMPING PERFORMANCE

PERFORMANCE PARAMETERS vs TIME

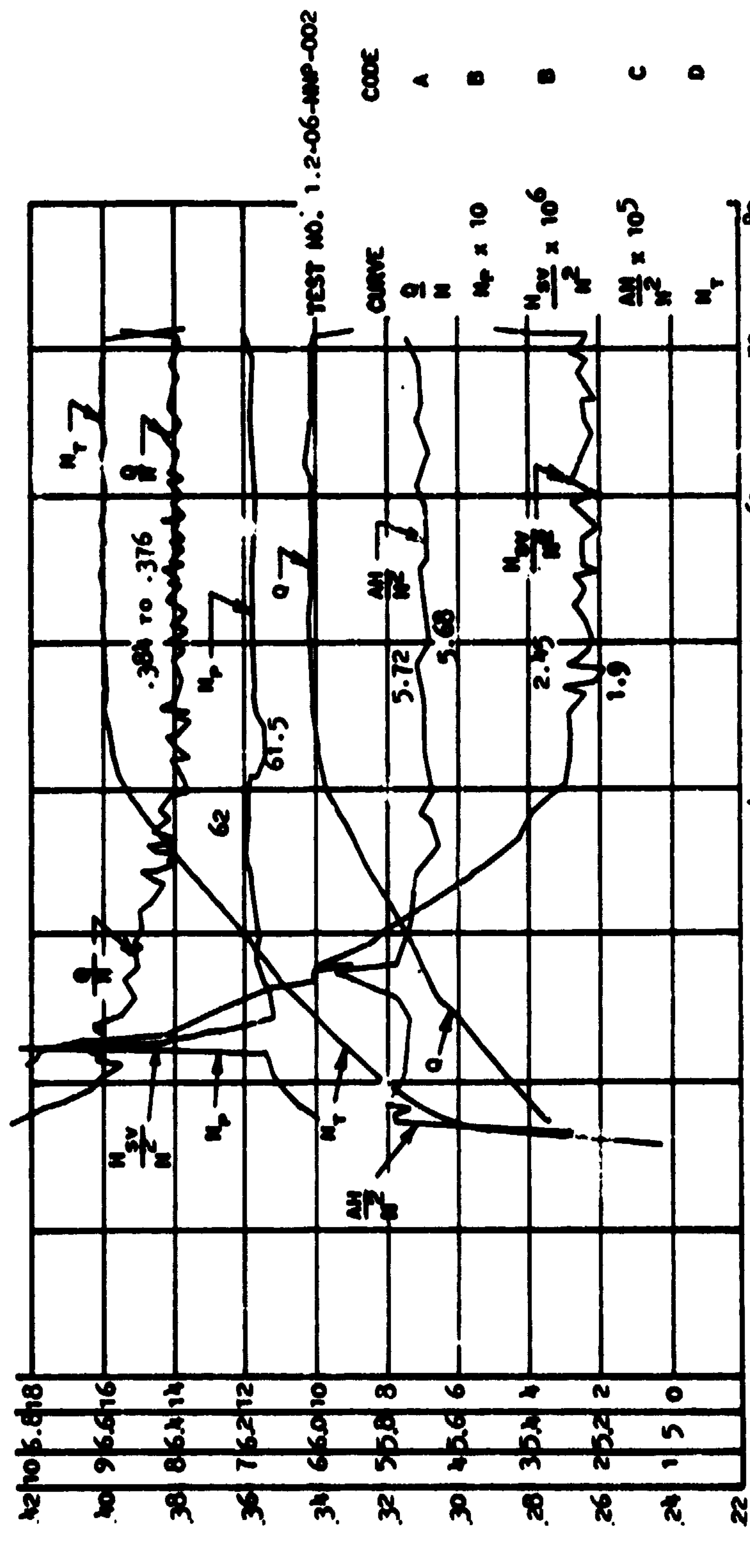


Figure 23

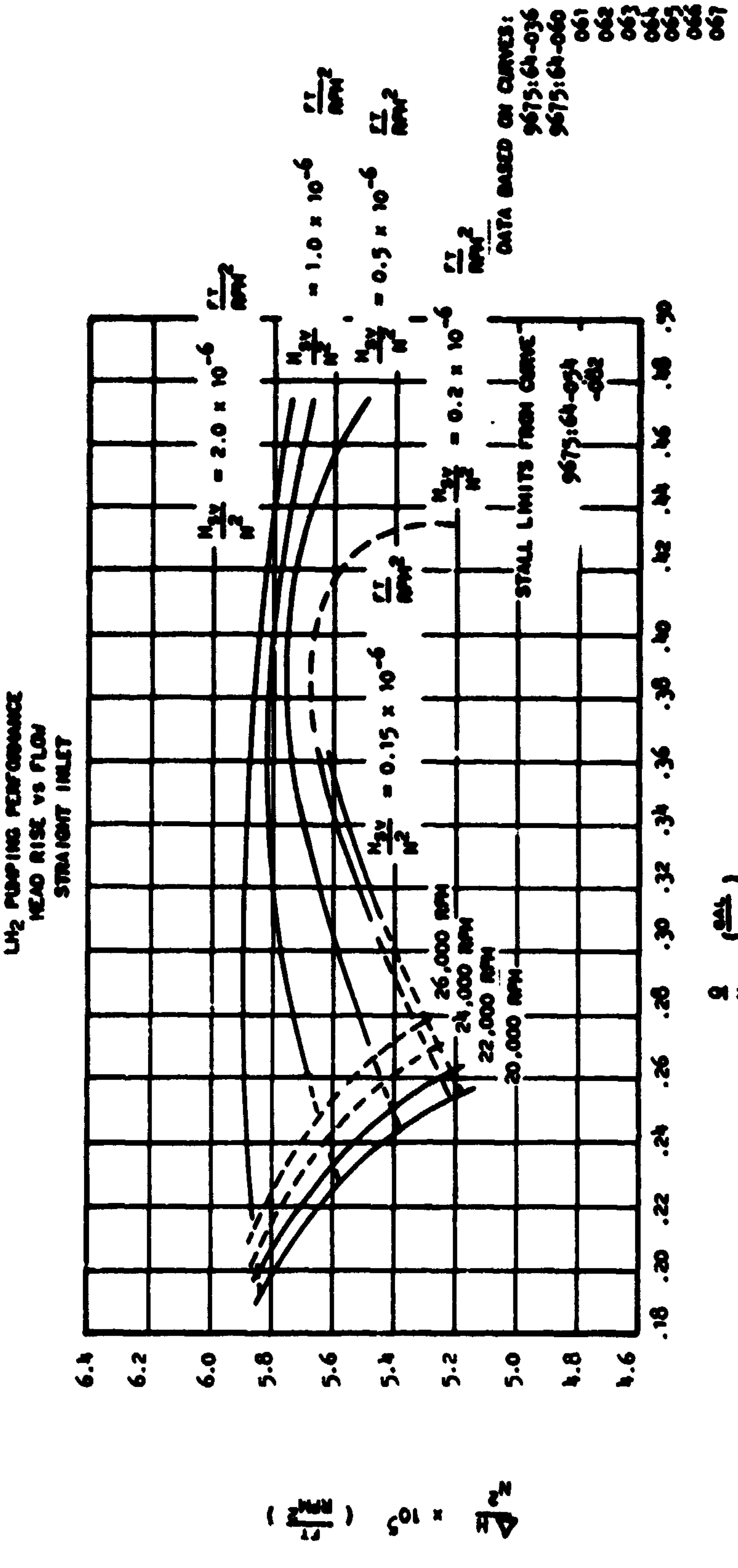

NERVA
MARK III TURBOPUMP
LH_2 PUMPING PERFORMANCE
HEAD RISE vs FLOW
STRAIGHT INLET
$\frac{\Delta H}{N^2} \times 10^5$ ($\frac{FT}{RPM^2}$)
6.4
6.2
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
.18 .20 .22 .24 .26 .28 .30 .32 .34 .36 .38 .40 .42 .44 .46 .48 .50
$\frac{Q}{N}$ ($\frac{GAL}{REV}$)
$\frac{H_{SV}}{N^2} = 2.0 \times 10^{-6}$ $\frac{FT}{RPM^2}$
$\frac{H_{SV}}{N^2} = 1.0 \times 10^{-6}$ $\frac{FT}{RPM^2}$
$\frac{H_{SV}}{N^2} = 0.5 \times 10^{-6}$ $\frac{FT}{RPM^2}$
$\frac{H_{SV}}{N^2} = 0.15 \times 10^{-6}$ $\frac{FT}{RPM^2}$
$\frac{H_{SV}}{N^2} = 0.2 \times 10^{-6}$ $\frac{FT}{RPM^2}$
26,000 RPM
24,000 RPM
22,000 RPM
20,000 RPM
STALL LIMITS FROM CURVE
9675:64-054
-082
DATA BASED ON CURVES:
9675:64-036
9675:64-060
061
062
063
064
065
066
067

Figure 24

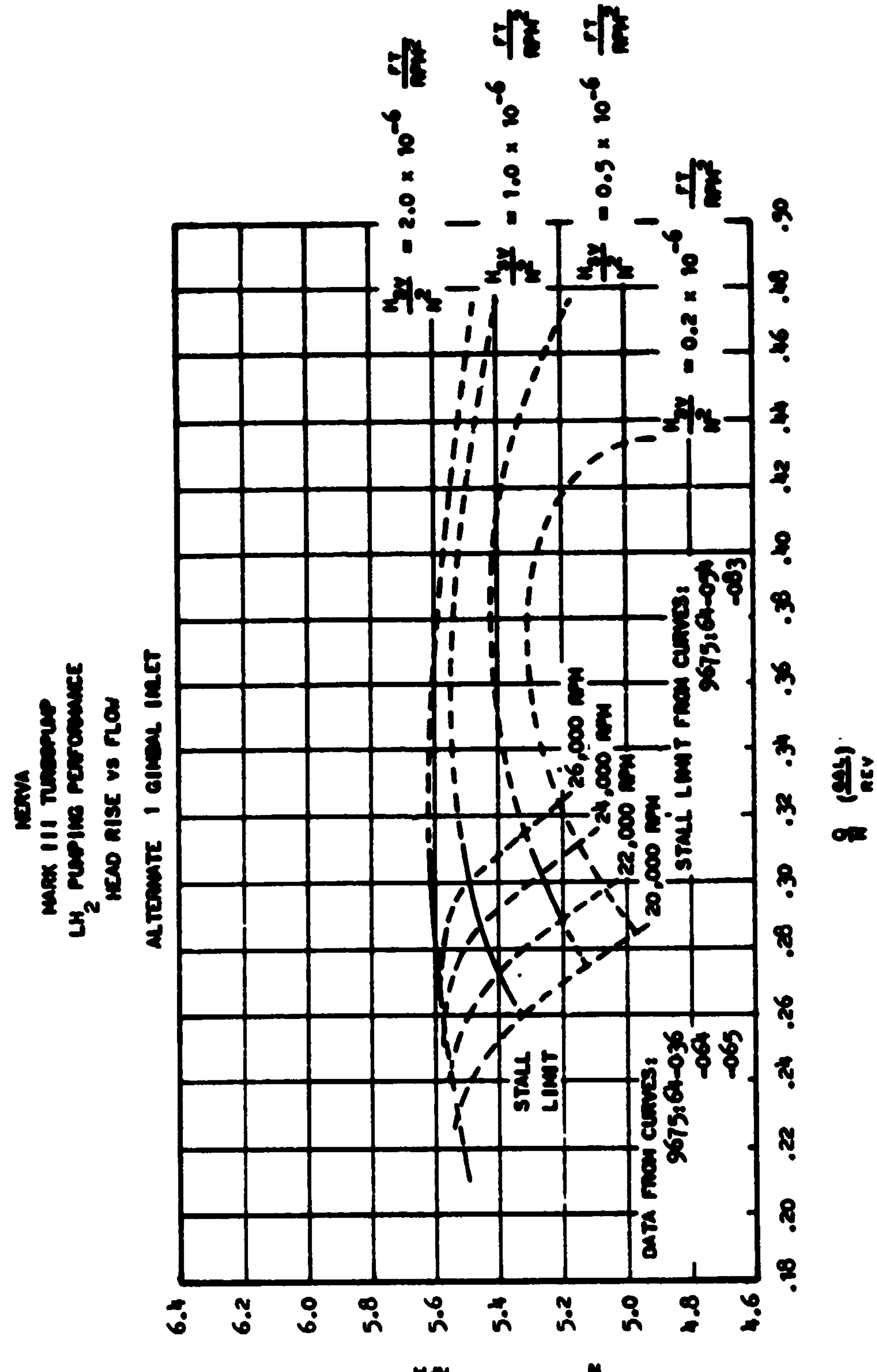

NERVA
MARK III TURBOPUMP
LH_2 PUMPING PERFORMANCE
HEAD RISE vs FLOW
ALTERNATE 1 GIMBAL INLET
$\frac{N_{SV}}{N^2} = 2.0 \times 10^{-6}$ $\frac{FT}{RPM^2}$
$\frac{N_{SV}}{N^2} = 1.0 \times 10^{-6}$ $\frac{FT}{RPM^2}$
$\frac{N_{SV}}{N^2} = 0.5 \times 10^{-6}$ $\frac{FT}{RPM^2}$
$\frac{N_{SV}}{N^2} = 0.2 \times 10^{-6}$ $\frac{FT}{RPM^2}$
26,000 RPM
24,000 RPM
22,000 RPM
20,000 RPM
STALL LIMIT
DATA FROM CURVES: 9675;04-036 -064 -065
STALL LIMIT FROM CURVES: 9675;04-094 -083
$\frac{\Delta H}{N^2} \times 10^5$ $\left(\frac{FT}{RPM^2}\right)$
$\frac{Q}{N}$ $\left(\frac{GAL}{REV}\right)$
6.4
6.2
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
.18
.20
.22
.24
.26
.28
.30
.32
.34
.36
.38
.40
.42
.44
.46
.48
.50

Figure 25

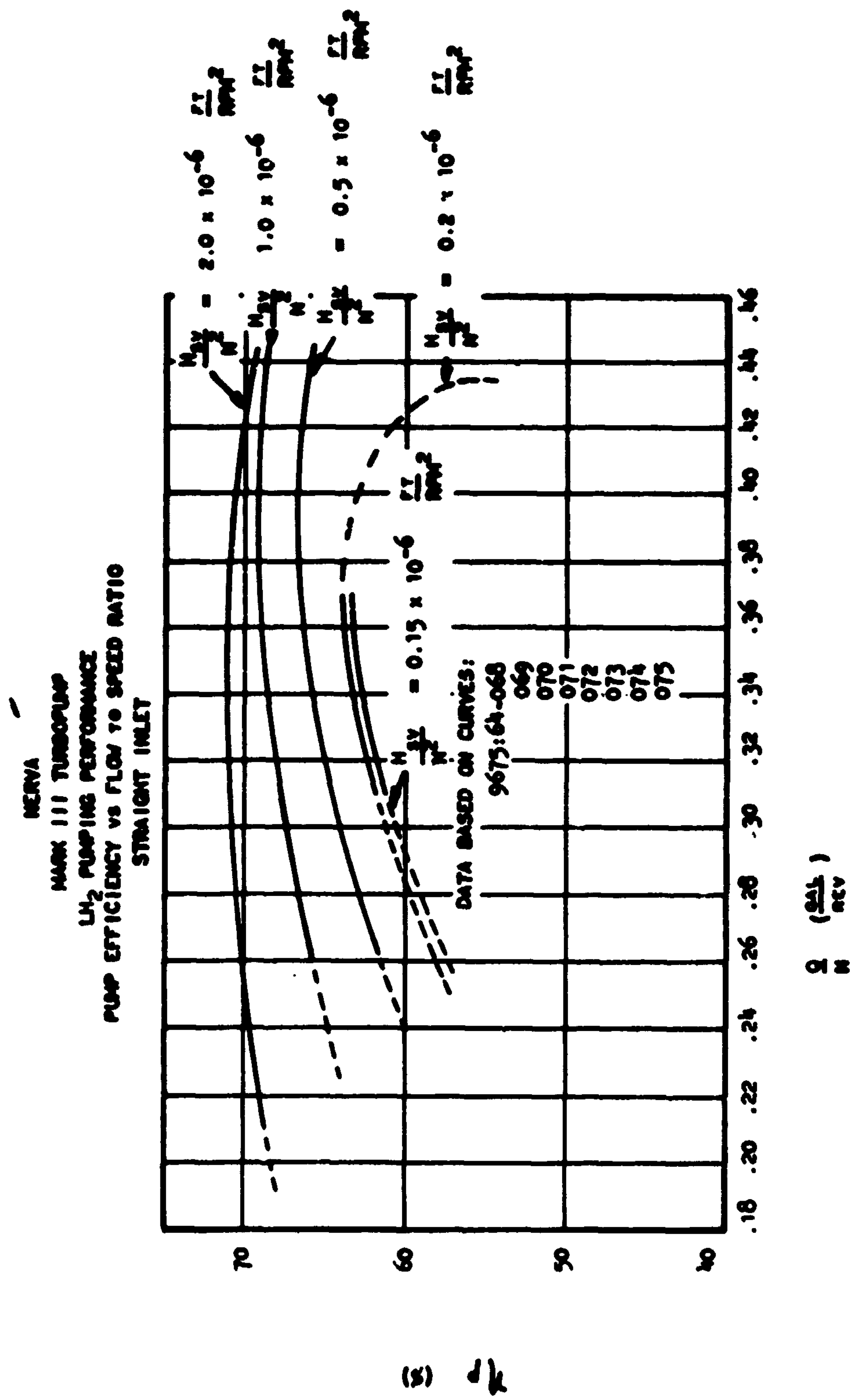

NERVA
MARK III TURBOPUMP
LH_2 PUMPING PERFORMANCE
PUMP EFFICIENCY vs FLOW TO SPEED RATIO
STRAIGHT INLET
$\frac{N_{SV}}{N^2} = 2.0 \times 10^{-6} \frac{FT}{RPM^2}$
$\frac{N_{SV}}{N^2} = 1.0 \times 10^{-6} \frac{FT}{RPM^2}$
$\frac{N_{SV}}{N^2} = 0.5 \times 10^{-6} \frac{FT}{RPM^2}$
$\frac{N_{SV}}{N^2} = 0.2 \times 10^{-6} \frac{FT}{RPM^2}$
$\frac{N_{SV}}{N^2} = 0.15 \times 10^{-6} \frac{FT}{RPM^2}$
DATA BASED ON CURVES:
9675:64-068
069
070
071
072
073
074
075
.18 .20 .22 .24 .26 .28 .30 .32 .34 .36 .38 .40 .42 .44 .46
$\frac{Q}{N}$ $(\frac{GAL}{REV})$
70
60
50
40
η_P (%)

Figure 26

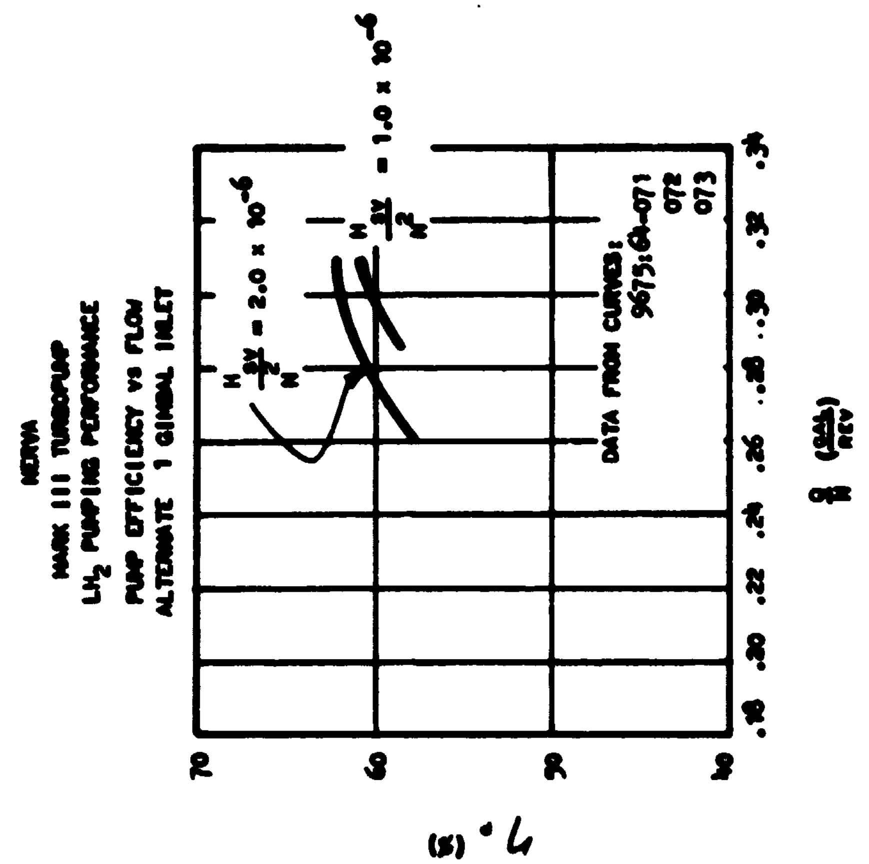

NERVA
MARK III TURBOPUMP
LH_2 PUMPING PERFORMANCE
PUMP EFFICIENCY VS FLOW
ALTERNATE 1 GIMBAL INLET
$\frac{H}{N^2} \frac{\Omega V}{} = 2.0 \times 10^{-6}$
$\frac{H}{N^2} \frac{\Omega V}{} = 1.0 \times 10^{-6}$
DATA FROM CURVES:
9675:69-071
072
073
70
60
50
40
.18
.20
.22
.24
.26
.28
.30
.32
.34
$\frac{Q}{N}$ $\left(\frac{GAL}{REV}\right)$
η, (%)

Figure 27

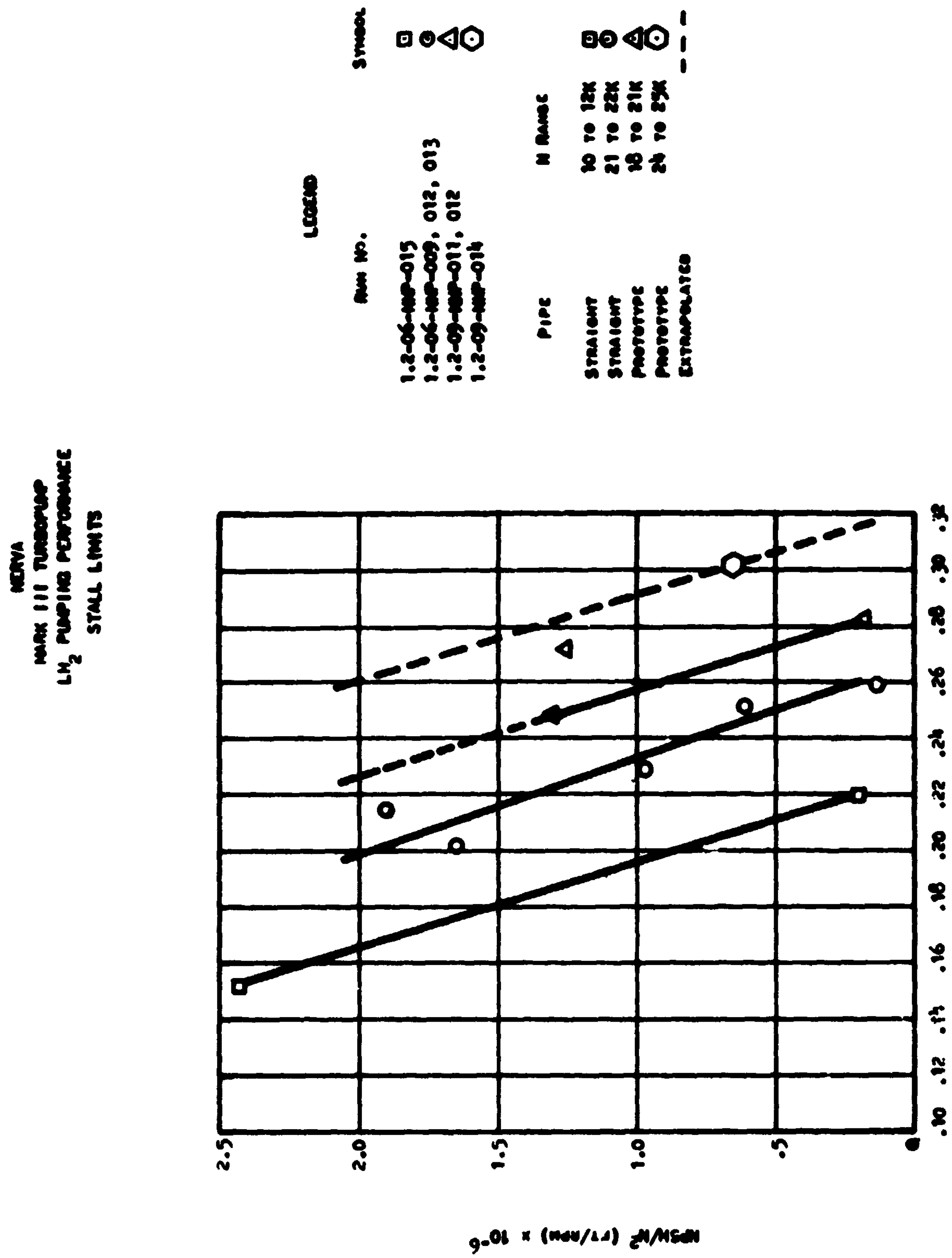

NERVA
MARK III TURBOPUMP
LH2 PUMPING PERFORMANCE
STALL LIMITS
LEGEND
RUN NO.
SYMBOL
1.2-06-MKP-015
1.2-06-MKP-009, 012, 013
1.2-09-MKP-011, 012
1.2-09-MKP-014
PIPE
N RANGE
STRAIGHT
10 TO 12K
STRAIGHT
21 TO 22K
PROTOTYPE
18 TO 21K
PROTOTYPE
24 TO 25K
EXTRAPOLATED
2.5
2.0
1.5
1.0
.5
0
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
.30
.32
NPSH/N² (FT/RPM) x 10⁻⁶

Figure 28

Cross Section Pump Housing S/N 1911

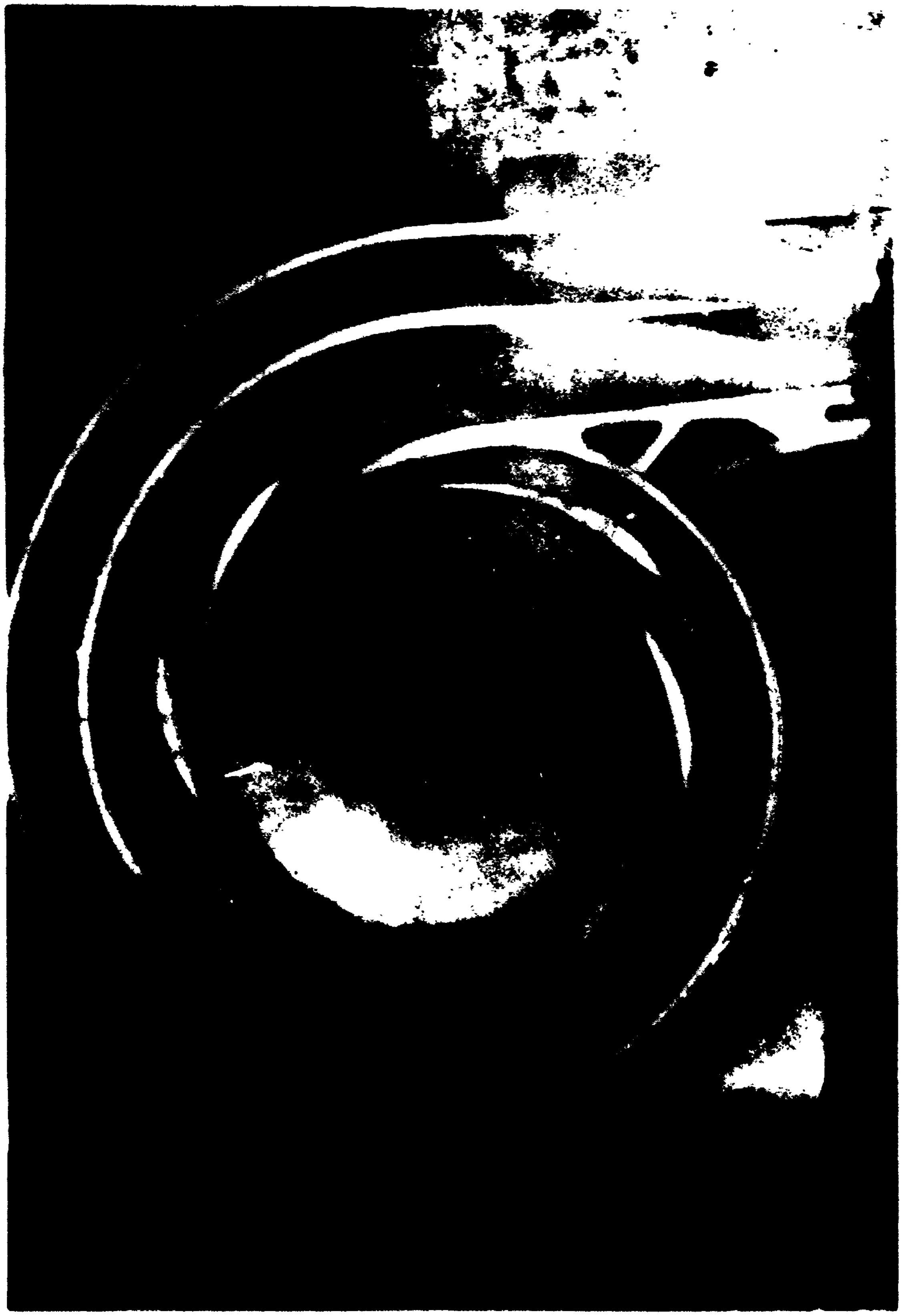


Figure 29

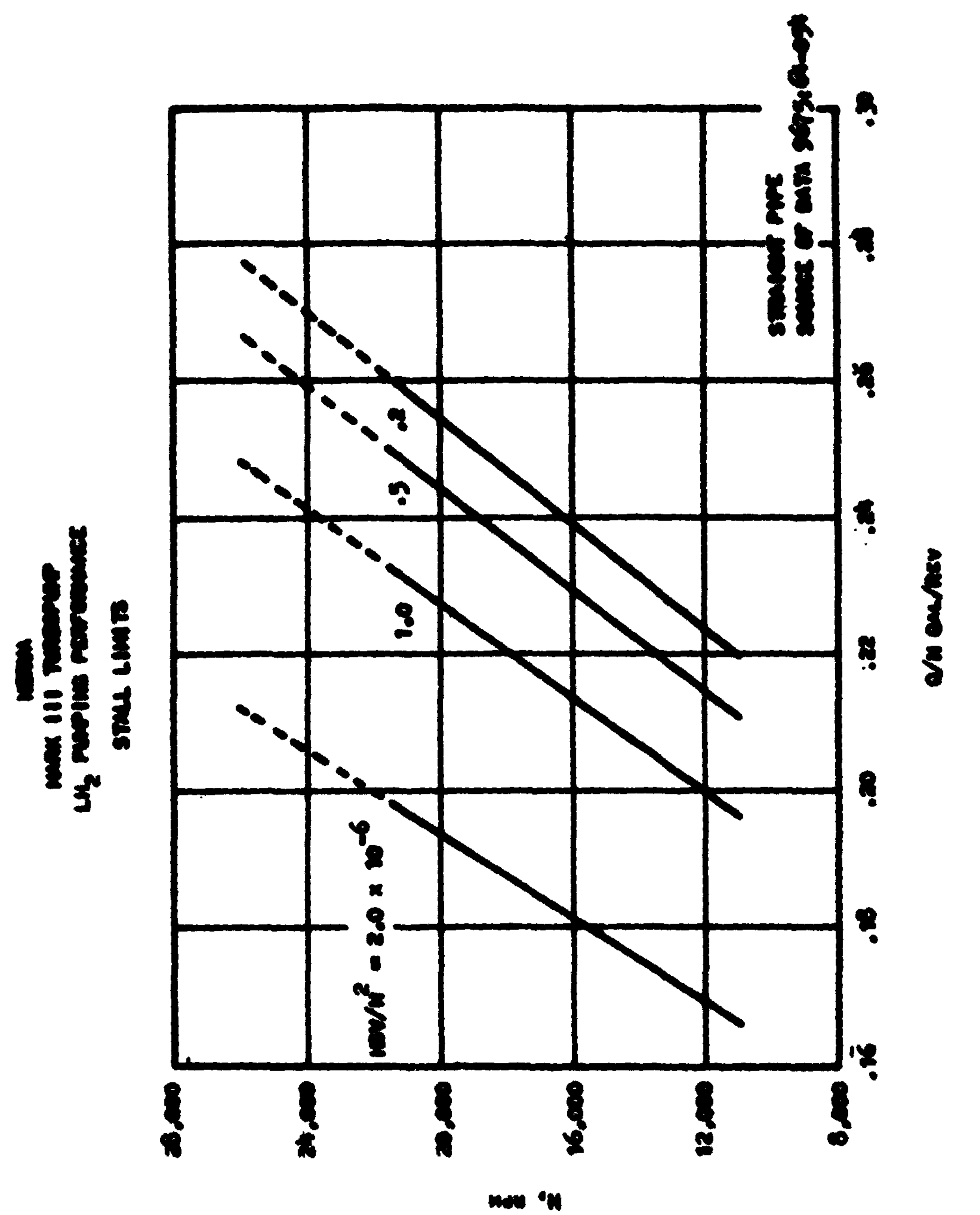

MARK III TURBOPUMP
STALL LIMITS
STRAIGHT PIPE
Q/N GAL/REV
N, RPM
28,000
24,000
20,000
16,000
12,000
8,000
.16
.18
.20
.22
.24
.26
.28
.30
NPSH/N² = 2.0 x 10⁻⁶
1.0
.5
.2

Figure 30

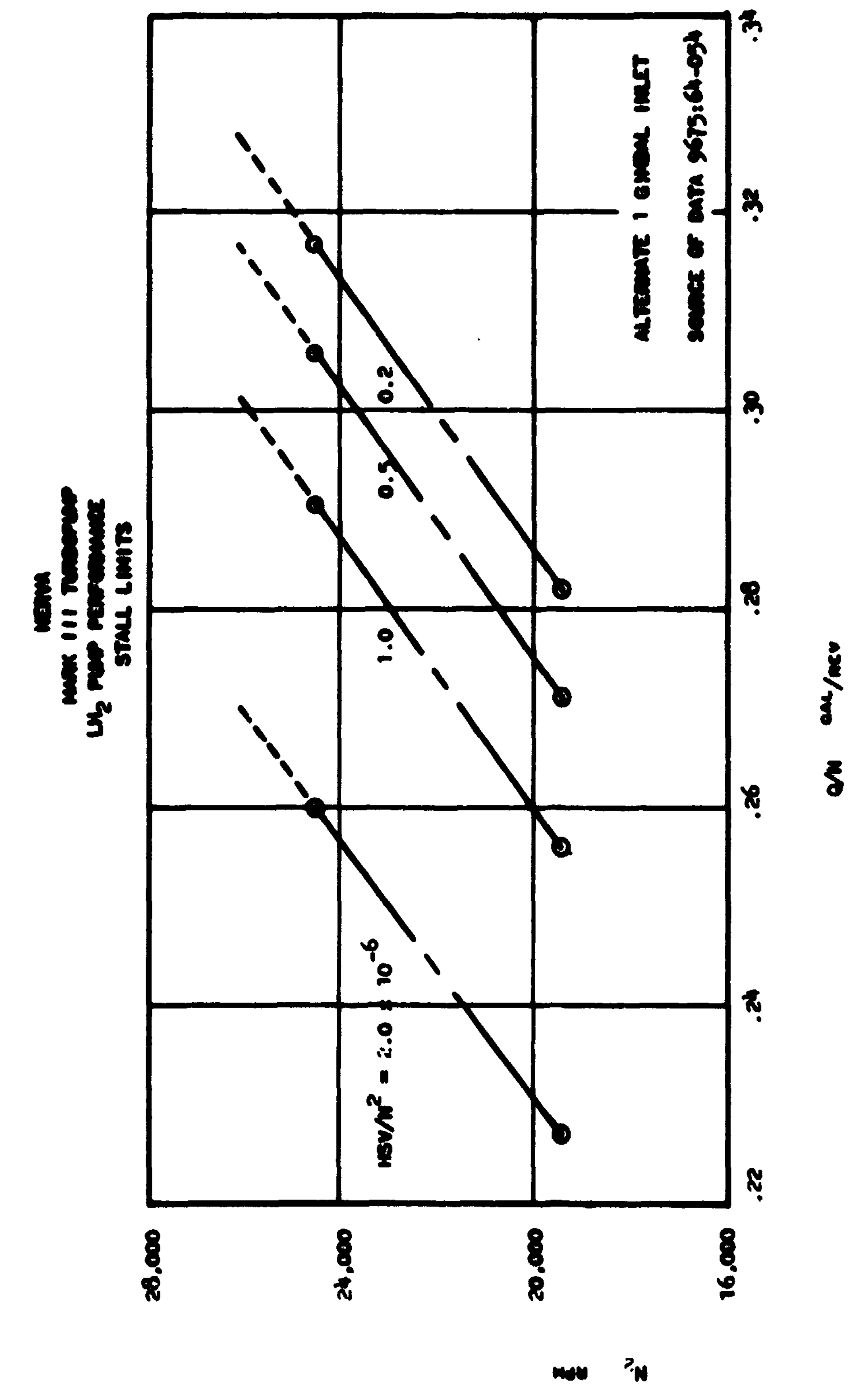

NERVA
MARK III TURBOPUMP
LH2 PUMP PERFORMANCE
STALL LIMITS
ALTERNATE 1 GIMBAL INLET
HSV/N^2 = 2.0 x 10^-6
1.0
0.5
0.2
28,000
24,000
20,000
16,000
N, RPM
.22
.24
.26
.28
.30
.32
.34
Q/N GAL/REV

Figure 31

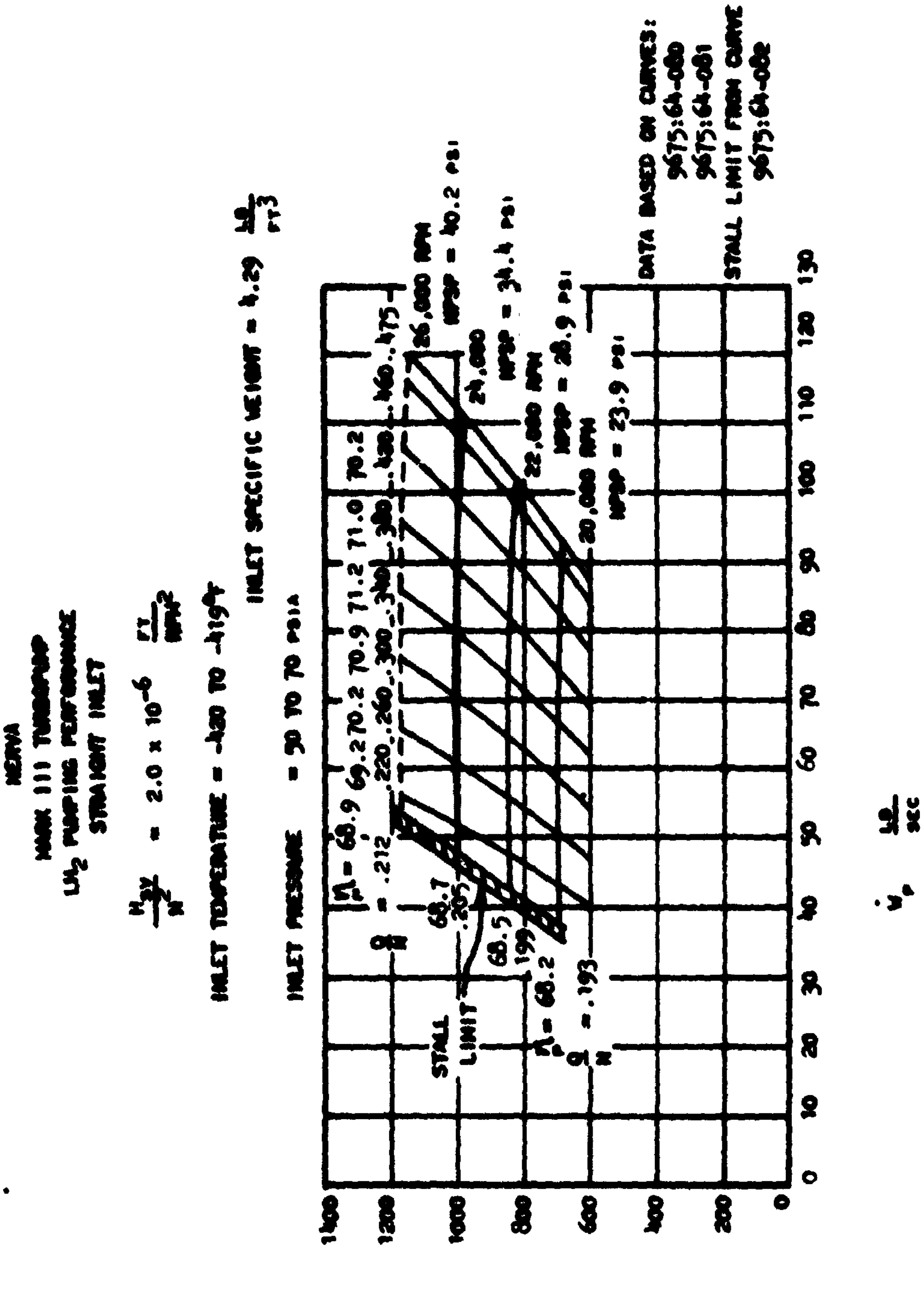

NERVA
MARK III TURBOPUMP
LH2 PUMPING PERFORMANCE
STRAIGHT INLET
INLET PRESSURE = 50 TO 70 PSIA
STALL LIMIT
DATA BASED ON CURVES:
STALL LIMIT FROM CURVE

Figure 32

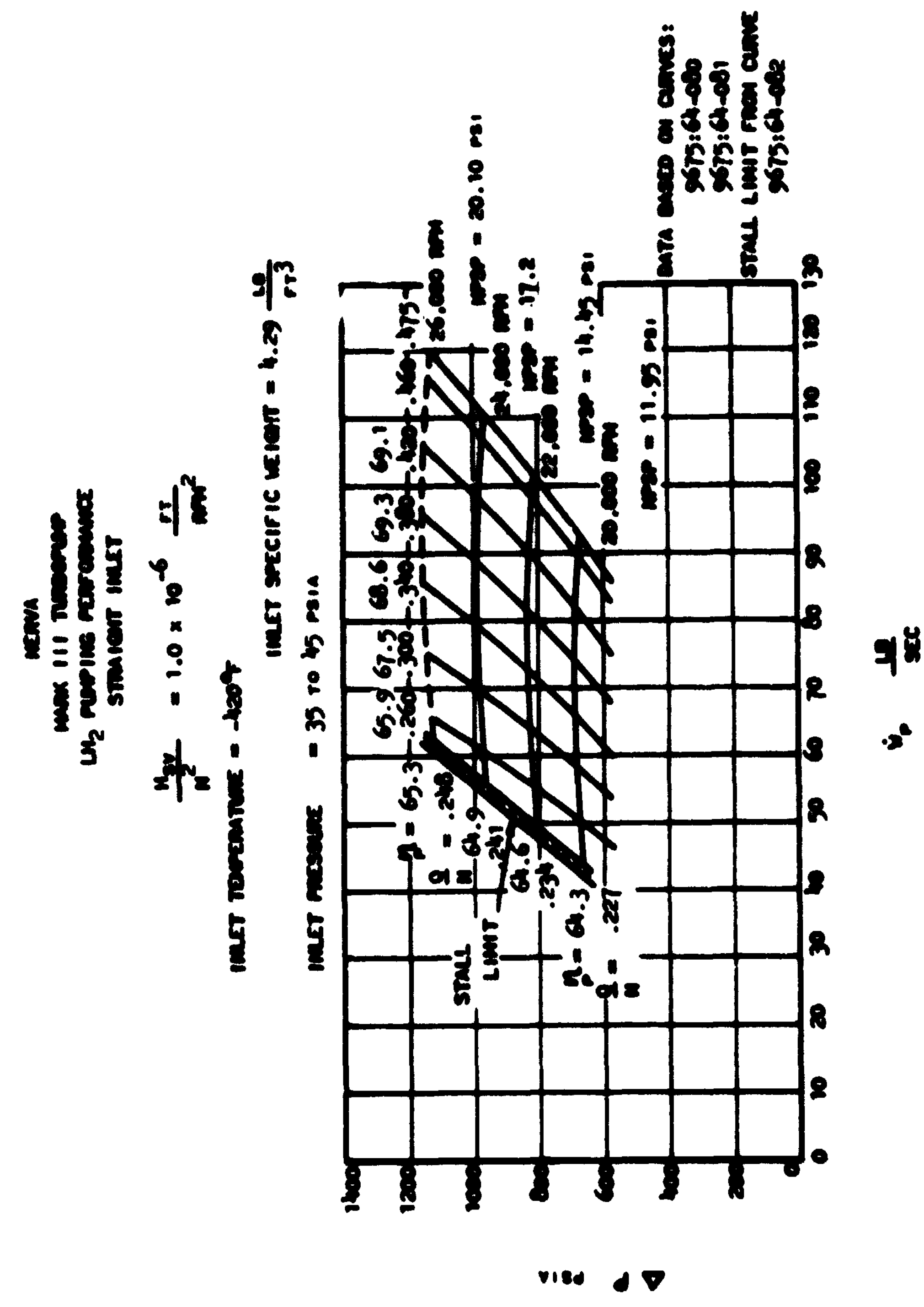

NERVA
MARK III TURBOPUMP
LH2 PUMPING PERFORMANCE
STRAIGHT INLET
INLET TEMPERATURE = -420°F
INLET SPECIFIC WEIGHT = 4.29 LB/FT3
INLET PRESSURE = 35 TO 45 PSIA
DATA BASED ON CURVES:
9675:64-080
9675:64-081
STALL LIMIT FROM CURVE
9675:64-082
STALL LIMIT
26,000 RPM
24,000 RPM
22,000 RPM
20,000 RPM
NPSP = 20.10 PSI
NPSP = 17.2
NPSP = 14.45 PSI
NPSP = 11.95 PSI
Δ P PSIA
LB/SEC

Figure 33

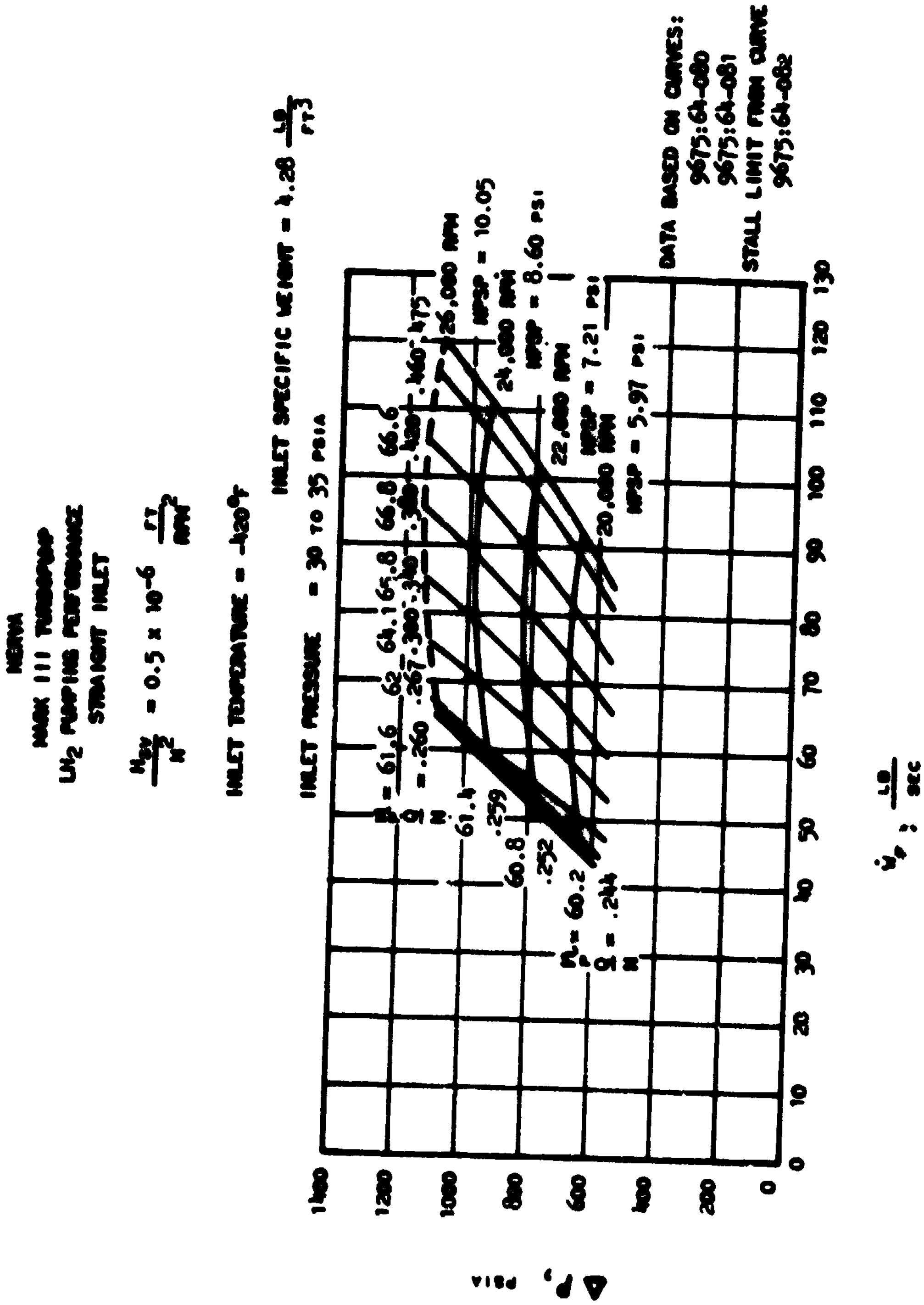

NERVA
MARK III TURBOPUMP
LH_2 PUMPING PERFORMANCE
STRAIGHT INLET
$\frac{H_{SV}}{N^2} = 0.5 \times 10^{-6}$ $\frac{FT}{RPM^2}$
INLET TEMPERATURE = -420°F
INLET PRESSURE = 30 TO 35 PSIA
INLET SPECIFIC WEIGHT = 4.28 $\frac{LB}{FT^3}$
DATA BASED ON CURVES:
9675:64-080
9675:64-081
STALL LIMIT FROM CURVE
9675:64-082
26,000 RPM
NPSP = 10.05
24,000 RPM
NPSP = 8.60 PSI
22,000 RPM
NPSP = 7.21 PSI
20,000 RPM
NPSP = 5.97 PSI
η = 61.6 62 64.1 65.8 66.8 66.6
Q/N = .260 .267 .300 .340 .380 .420 .460 .475
η = 61.4 60.8 60.2
Q/N = .259 .252 .244
ΔP, PSIA
$\dot{W}_p$, $\frac{LB}{SEC}$
0 10 20 30 40 50 60 70 80 90 100 110 120 130
0 200 400 600 800 1000 1200 1400

Figure 34

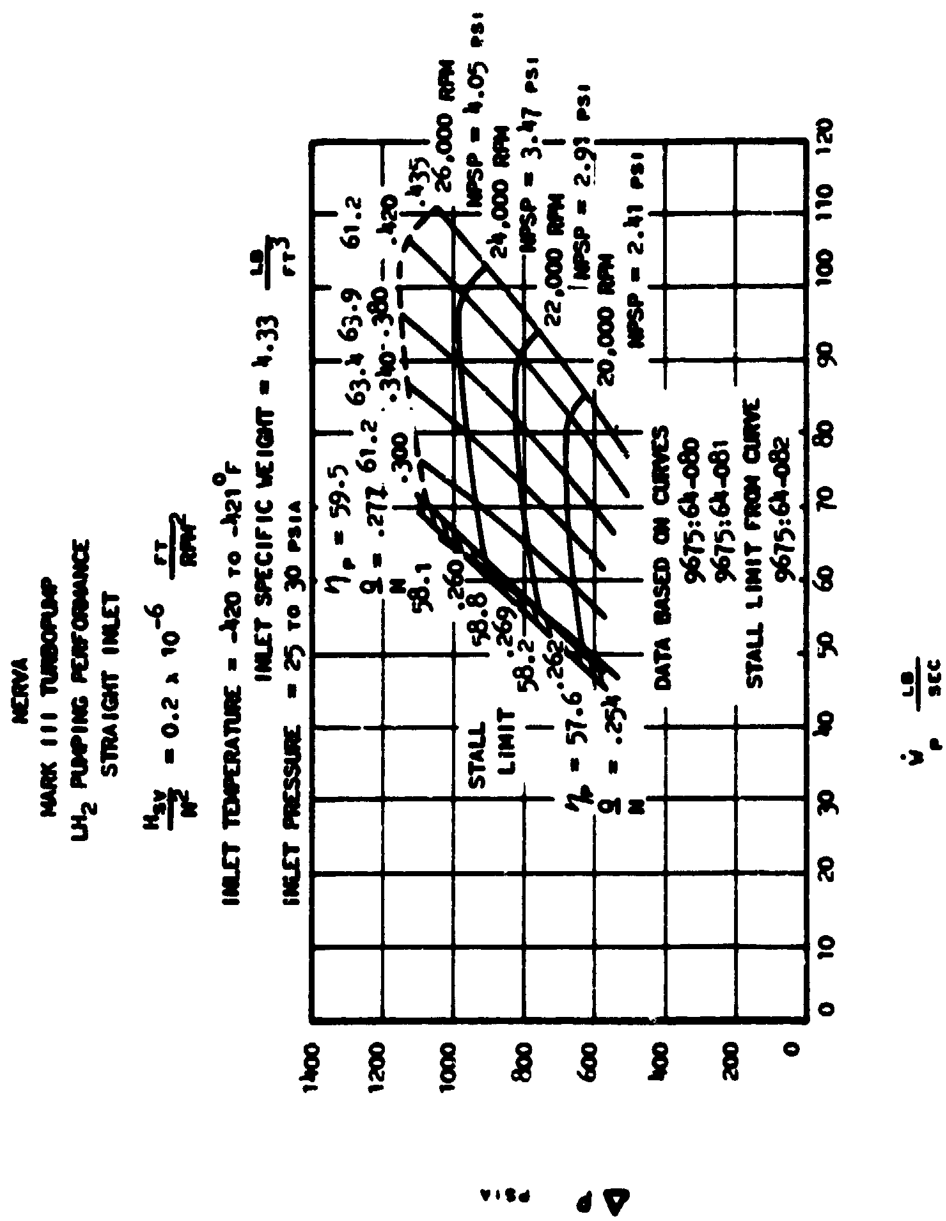

NERVA
MARK III TURBOPUMP
LH_2 PUMPING PERFORMANCE
STRAIGHT INLET
$\frac{H_{SV}}{N^2} = 0.2 \times 10^{-6}$ $\frac{FT}{RPM^2}$
INLET TEMPERATURE = -420 TO -421 °F
INLET SPECIFIC WEIGHT = 4.33 $\frac{LB}{FT^3}$
INLET PRESSURE = 25 TO 30 PSIA
STALL LIMIT
26,000 RPM
NPSP = 4.05 PSI
24,000 RPM
NPSP = 3.47 PSI
22,000 RPM
NPSP = 2.91 PSI
20,000 RPM
NPSP = 2.41 PSI
DATA BASED ON CURVES
9675:64-080
9675:64-081
STALL LIMIT FROM CURVE
9675:64-082
ΔP PSIA
$\dot{W}_P$ $\frac{LB}{SEC}$

Figure 35

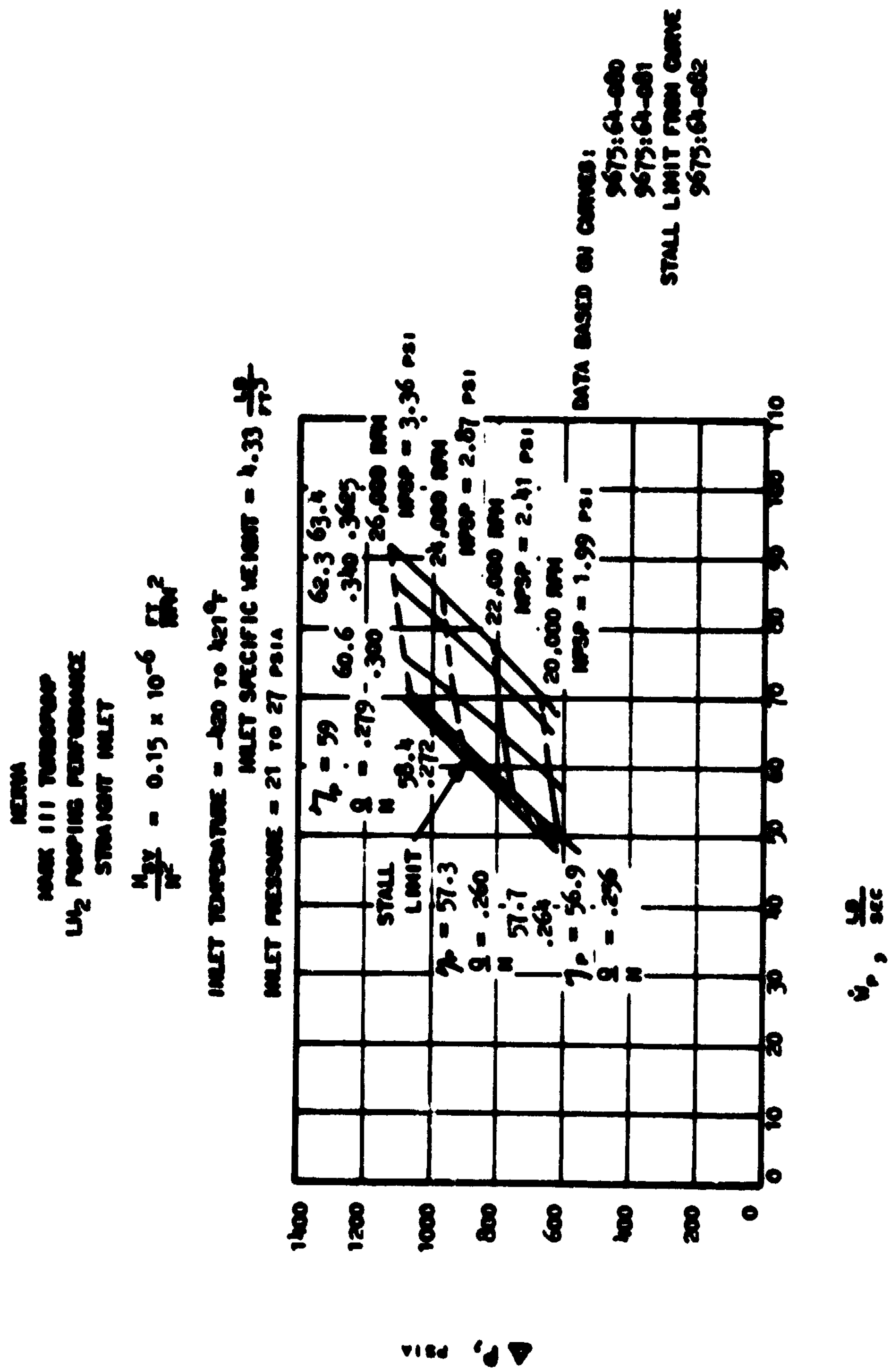
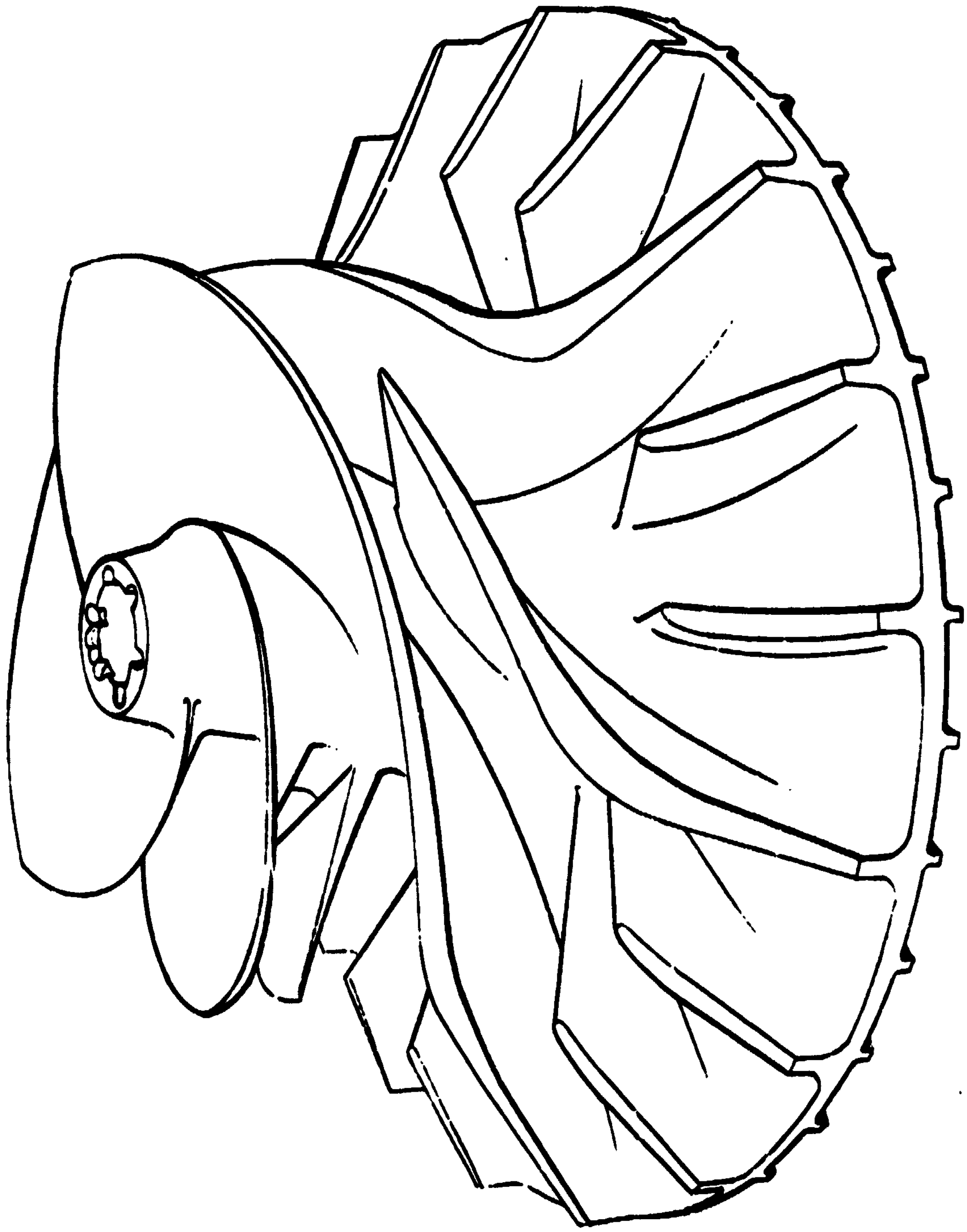

NERVA
MARK III TURBOPUMP
LH2 PUMPING PERFORMANCE
STRAIGHT INLET
INLET TEMPERATURE = -420 TO 421°F
INLET SPECIFIC WEIGHT = 4.33 LB/FT3
INLET PRESSURE = 21 TO 27 PSIA
STALL LIMIT
26,000 RPM
NPSP = 3.36 PSI
24,000 RPM
NPSP = 2.87 PSI
22,000 RPM
NPSP = 2.41 PSI
20,000 RPM
NPSP = 1.99 PSI
DATA BASED ON CURVES:
9675:64-080
9675:64-081
STALL LIMIT FROM CURVE
9675:64-082
ΔP, PSIA
0
200
400
600
800
1000
1200
1400
0
10
20
30
40
50
60
70
80
90
100
110

Figure 36



PUMP IMPELLER

Figure 37

NERVA
MARK III MOD 3 TURBOPUMP
STRAIGHT INLET
DENSITY RATIO, DISCHARGE TO SUCTION VS
SUCTION HEAD

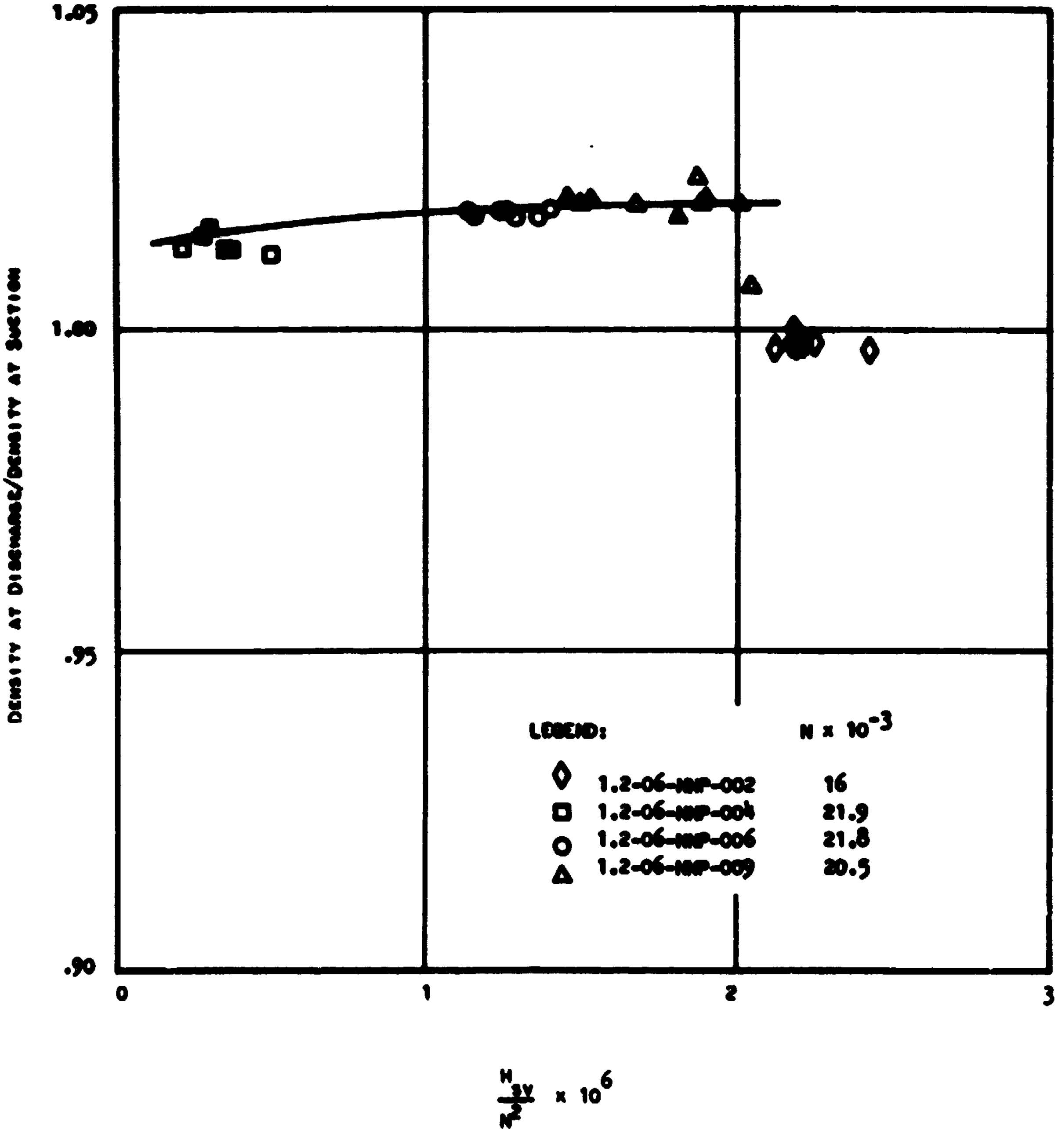


Figure 38

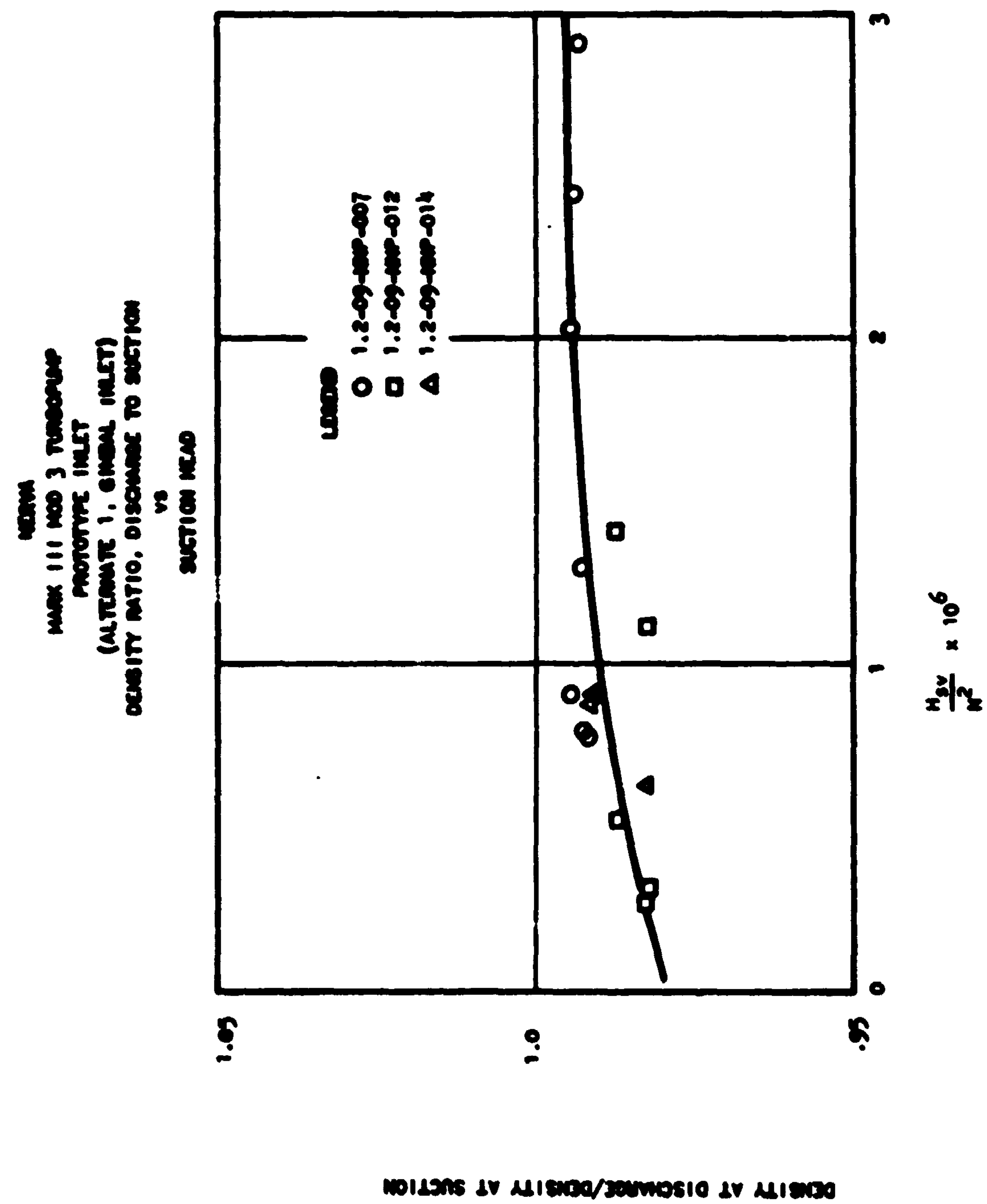

NERVA
MARK III MOD 3 TURBOPUMP
PROTOTYPE INLET
(ALTERNATE 1, GIMBAL INLET)
DENSITY RATIO, DISCHARGE TO SUCTION
VS
SUCTION HEAD
LEGEND
1.05
1.0
.95
0
1
2
3
DENSITY AT DISCHARGE/DENSITY AT SUCTION

Figure 39

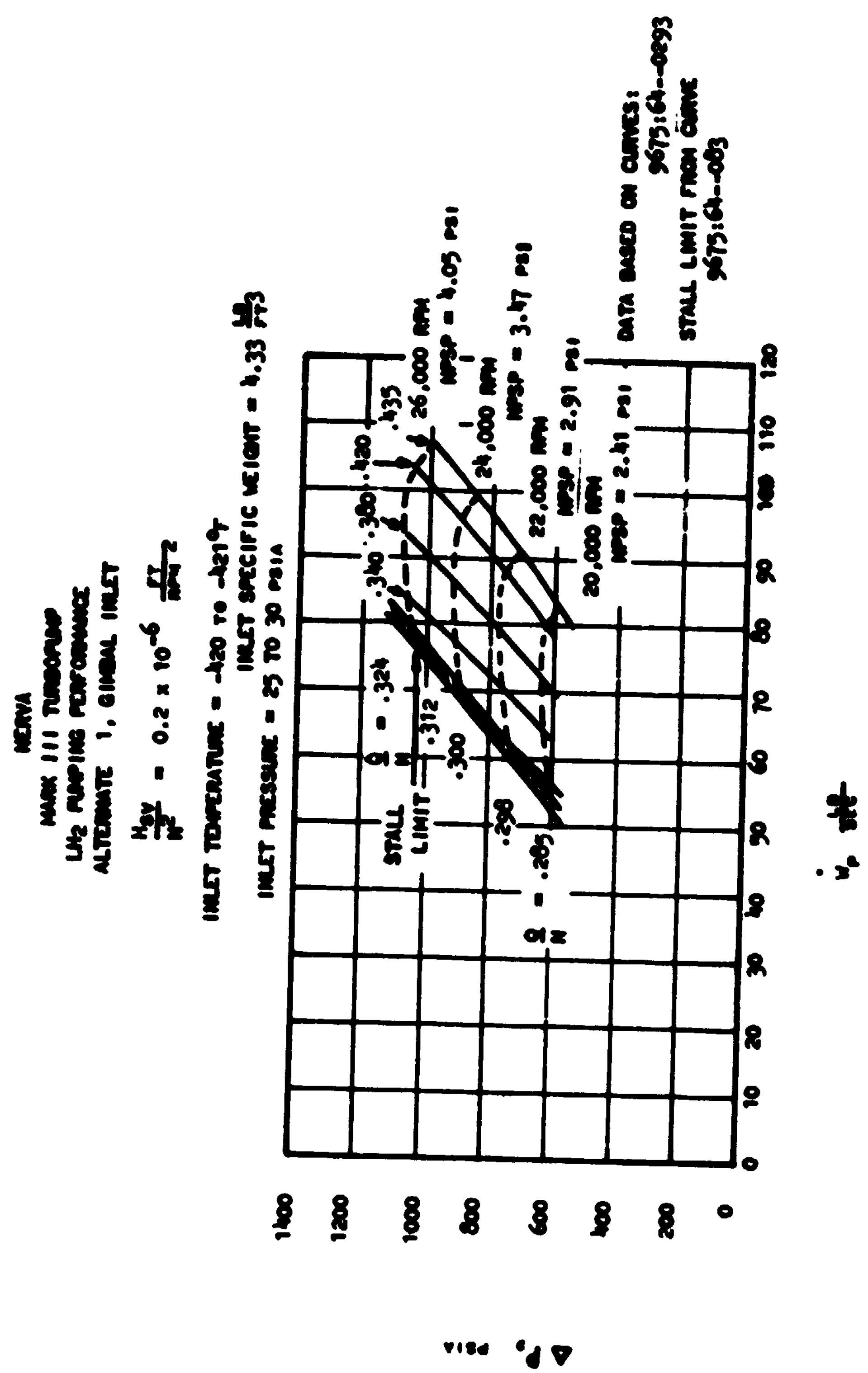

NERVA
MARK III TURBOPUMP
LH2 PUMPING PERFORMANCE
ALTERNATE 1, GIMBAL INLET
INLET TEMPERATURE = -420 TO -421°F
INLET SPECIFIC WEIGHT = 4.33 LB/FT3
INLET PRESSURE = 25 TO 30 PSIA
DATA BASED ON CURVES:
9673:64-0893
STALL LIMIT FROM CURVE
9673:64-083
26,000 RPM
NPSP = 4.05 PSI
24,000 RPM
NPSP = 3.47 PSI
22,000 RPM
NPSP = 2.91 PSI
20,000 RPM
NPSP = 2.41 PSI
STALL LIMIT
ΔP, PSIA
0 200 400 600 800 1000 1200 1400
0 10 20 30 40 50 60 70 80 90 100 110 120

Figure 40

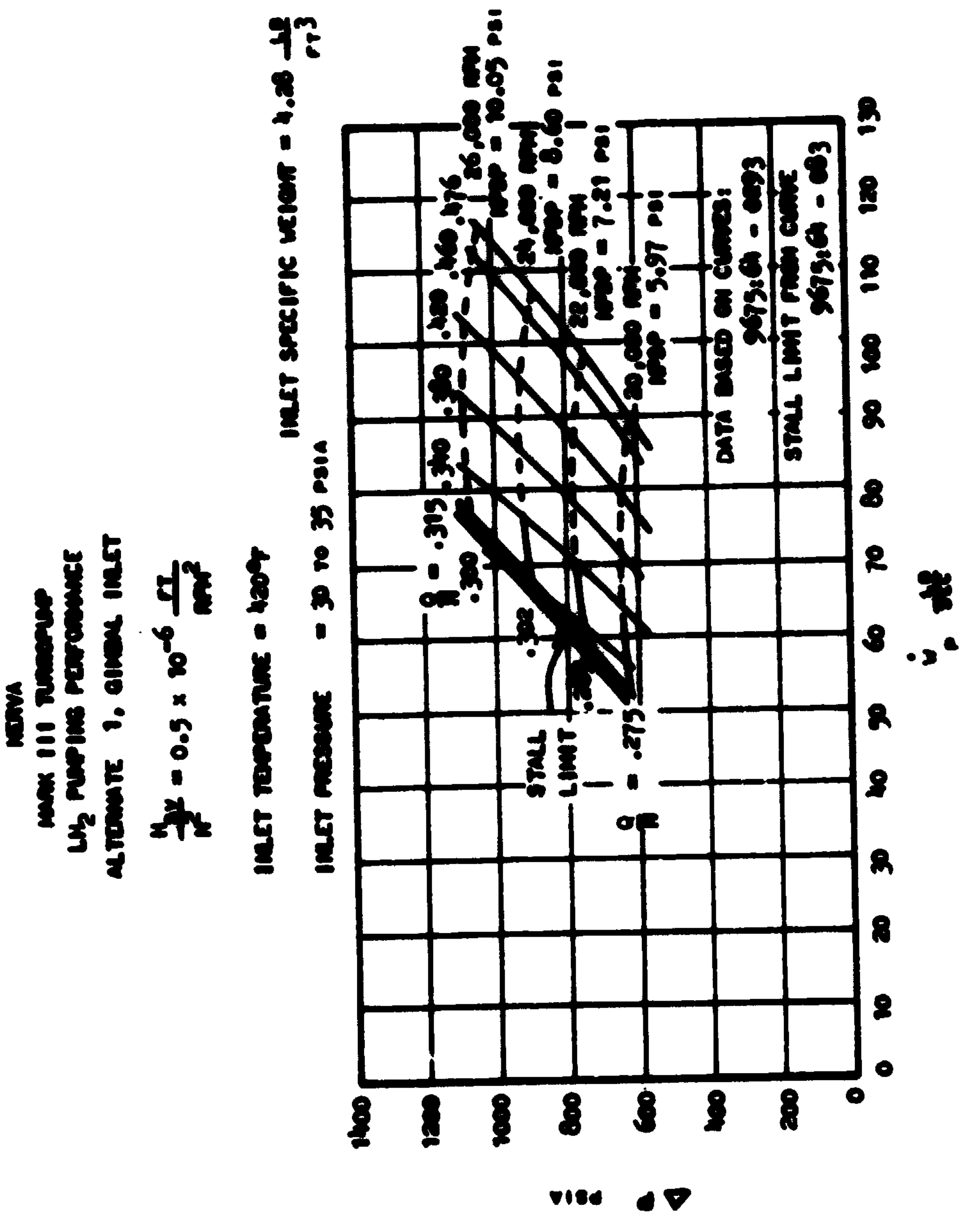

NERVA
MARK III TURBOPUMP
LH2 PUMPING PERFORMANCE
ALTERNATE 1, GIMBAL INLET
INLET PRESSURE = 30 TO 35 PSIA
STALL LIMIT
DATA BASED ON CURVES:
STALL LIMIT FROM CURVE
ΔP PSIA

Figure 41

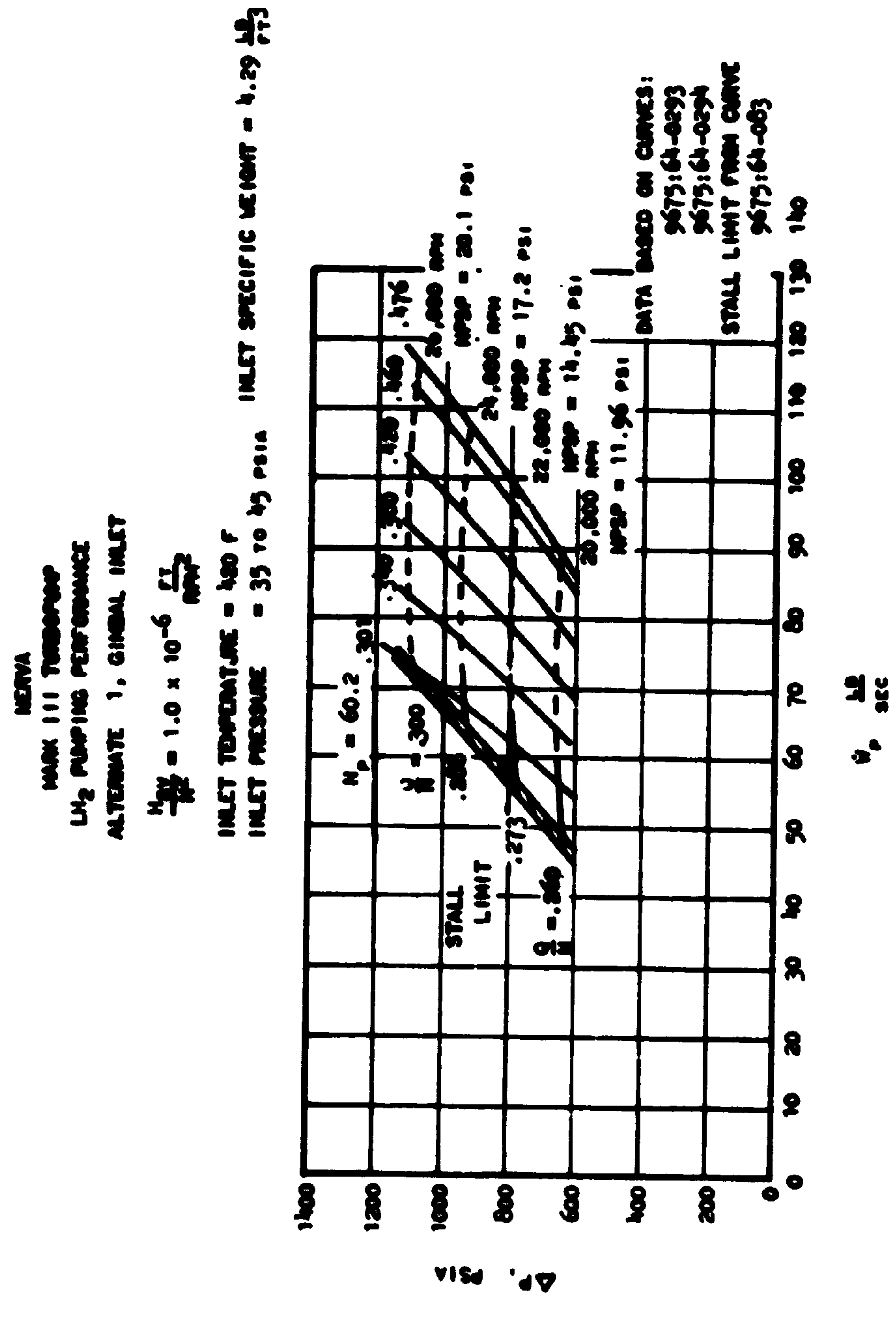

NERVA
MARK III TURBOPUMP
LH_2 PUMPING PERFORMANCE
ALTERNATE 1, GIMBAL INLET
INLET SPECIFIC WEIGHT = 4.29 LB/FT3
STALL LIMIT
DATA BASED ON CURVES:
9675:64-0293
9675:64-0294
STALL LIMIT FROM CURVE
9675:64-083
ΔP, PSIA

Figure 42

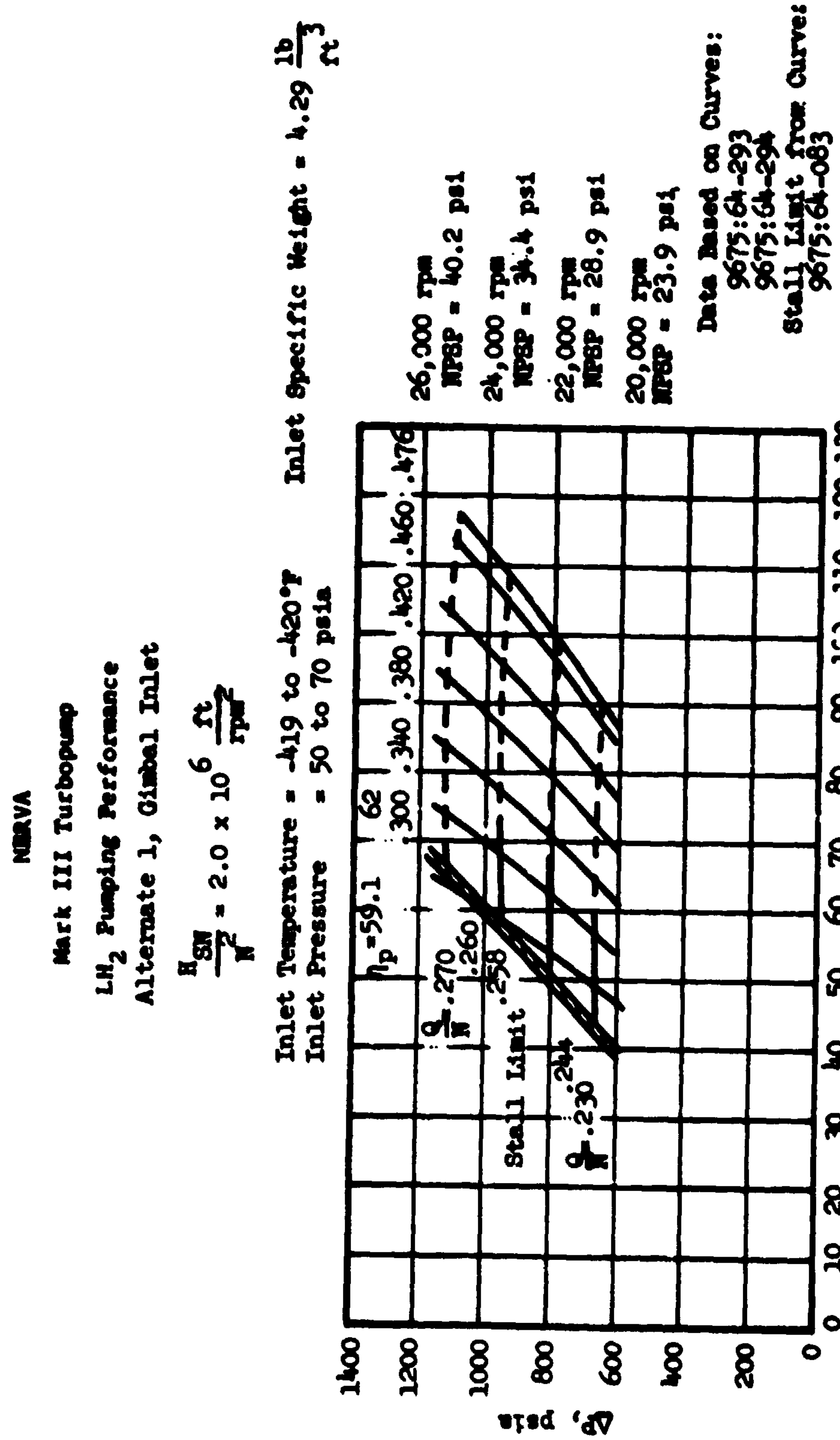

NERVA
Mark III Turbopump
LH_2 Pumping Performance
Alternate 1, Gimbal Inlet
$\frac{H_{SN}}{N^2} = 2.0 \times 10^6 \frac{ft}{rpm^2}$
Inlet Temperature = -419 to -420°F
Inlet Pressure = 50 to 70 psia
Inlet Specific Weight = 4.29 $\frac{lb}{ft^3}$
26,000 rpm
NPSP = 40.2 psi
24,000 rpm
NPSP = 34.4 psi
22,000 rpm
NPSP = 28.9 psi
20,000 rpm
NPSP = 23.9 psi
Data Based on Curves:
9675:64-293
9675:64-294
Stall Limit from Curve:
9675:64-083
η_p = 59.1
62
$\frac{Q}{N}$ .270
.260
.258
.244
.230
.300
.340
.380
.420
.460
.476
Stall Limit
ΔP, psia
$\dot{w}_p, \frac{lb}{sec}$

Figure 43

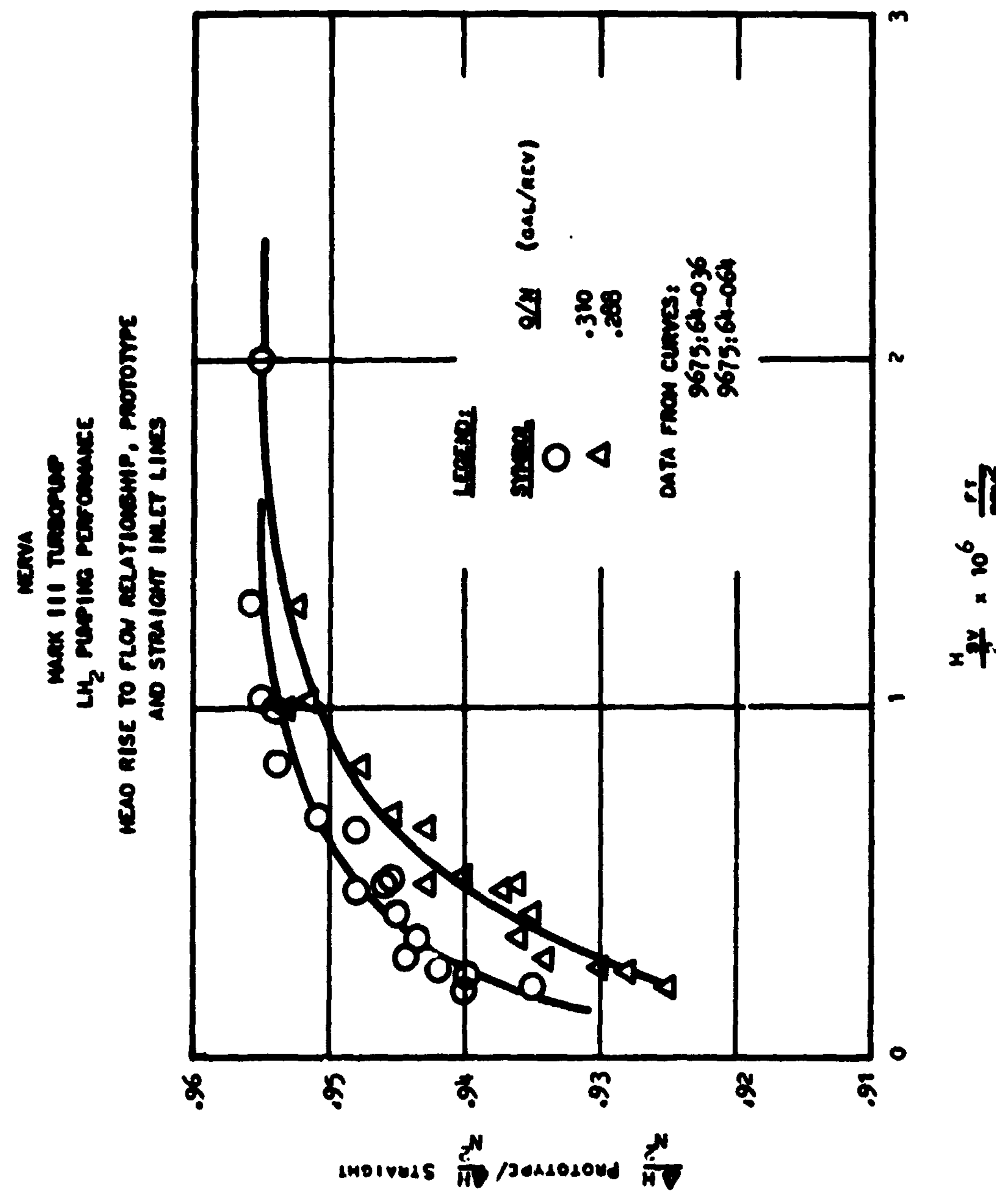

NERVA
MARK III TURBOPUMP
LH2 PUMPING PERFORMANCE
HEAD RISE TO FLOW RELATIONSHIP, PROTOTYPE
AND STRAIGHT INLET LINES
LEGEND:
SYMBOL
Q/N
(GAL/REV)
.310
.288
DATA FROM CURVES:
9675:64-036
9675:64-064
.96
.95
.94
.93
.92
.91
0
1
2
3
x 10^6
PROTOTYPE
STRAIGHT

Figure 44

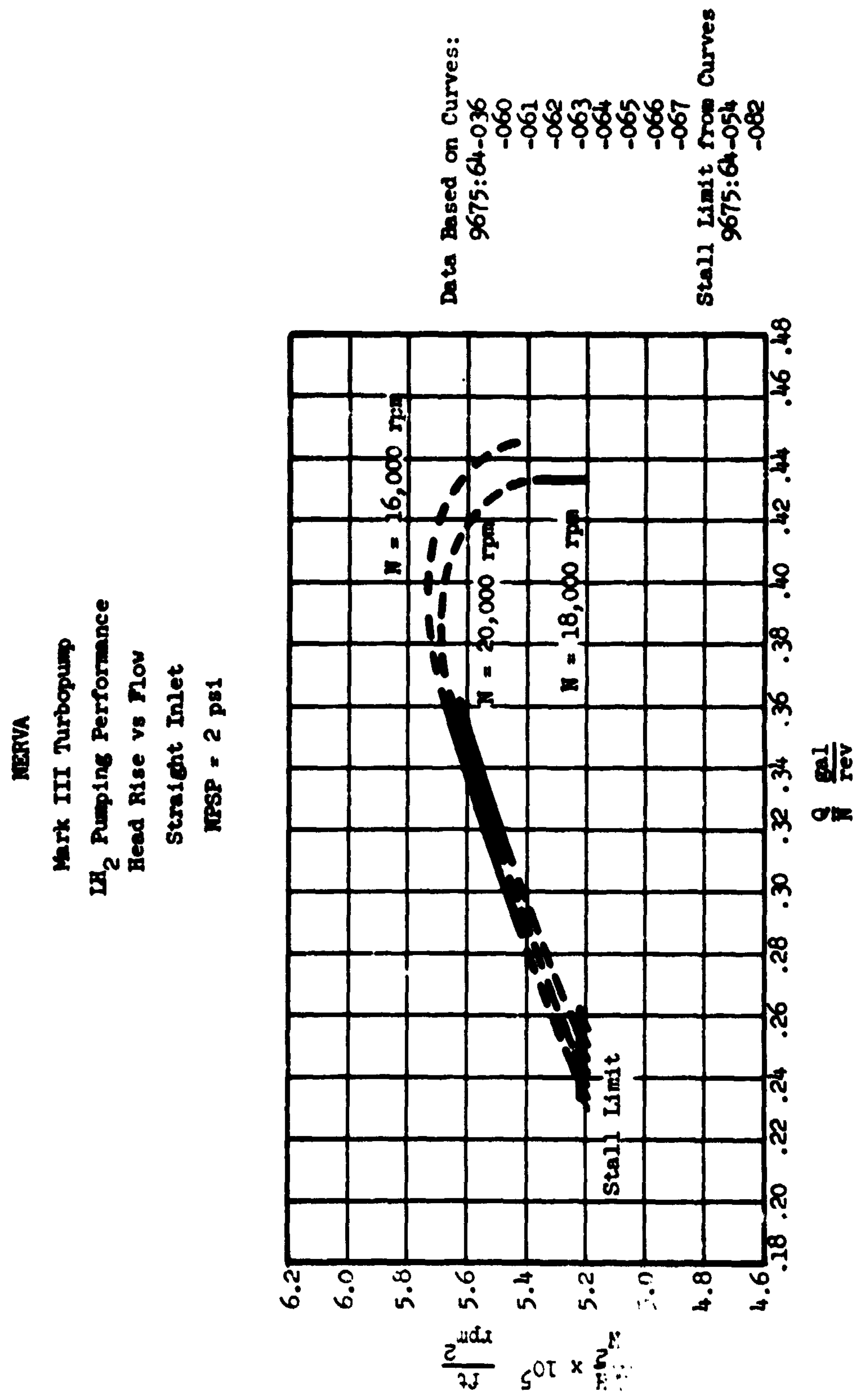

NERVA
Mark III Turbopump
LH_2 Pumping Performance
Head Rise vs Flow
Straight Inlet
NPSP = 2 psi
Data Based on Curves:
9675:64-036
-060
-061
-062
-063
-064
-065
-066
-067
Stall Limit from Curves
9675:64-054
-082
N = 16,000 rpm
N = 20,000 rpm
N = 18,000 rpm
Stall Limit
$\frac{Q}{N}$ $\frac{gal}{rev}$
.18
.20
.22
.24
.26
.28
.30
.32
.34
.36
.38
.40
.42
.44
.46
.48
6.2
6.0
5.8
5.6
5.4
5.2
4.8
4.6
$\frac{ft}{rpm^2}$
x 10^5

Figure 45

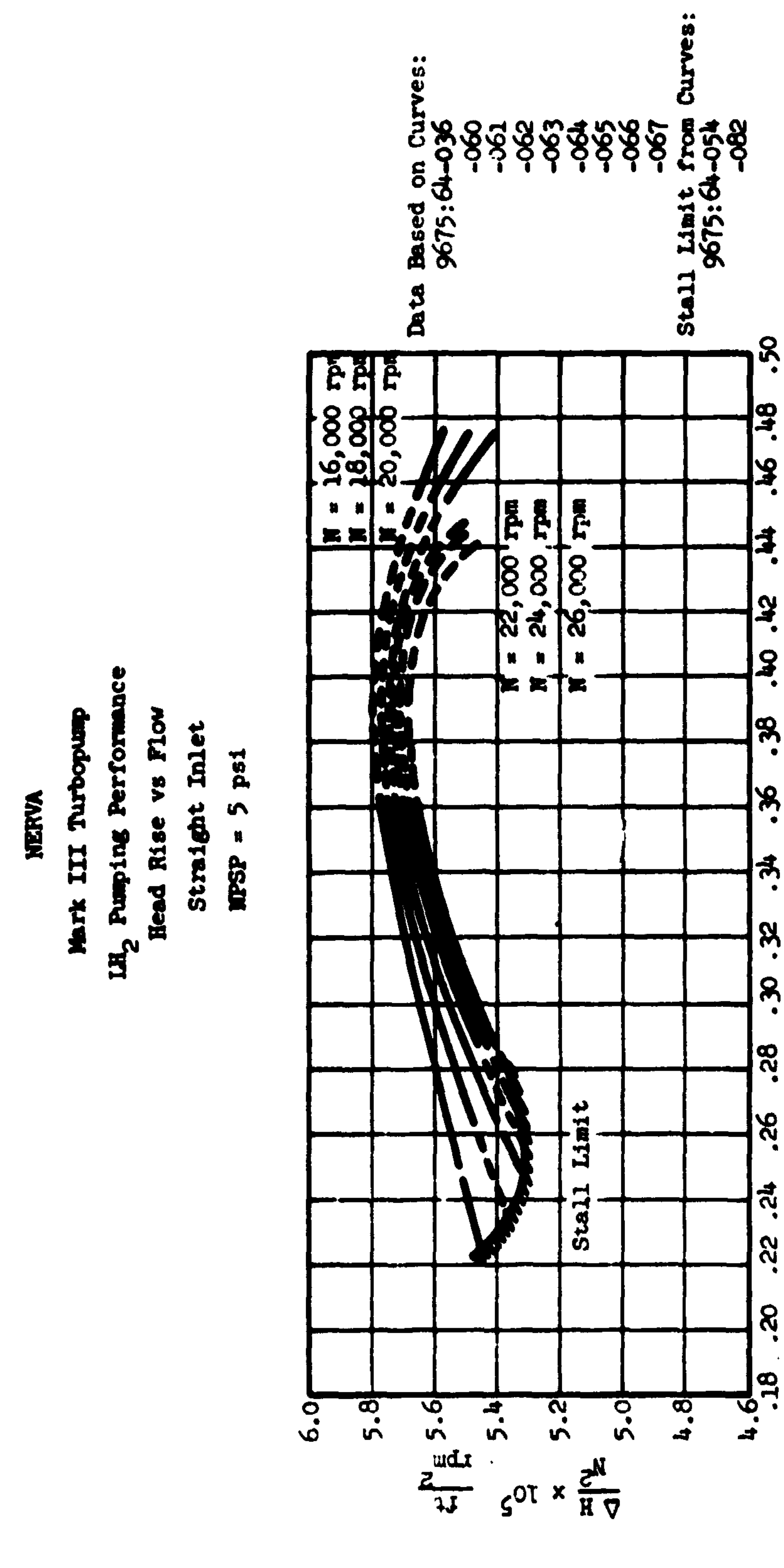

NERVA
Mark III Turbopump
LH_2 Pumping Performance
Head Rise vs Flow
Straight Inlet
NPSP = 5 psi
N = 16,000 rpm
N = 18,000 rpm
N = 20,000 rpm
N = 22,000 rpm
N = 24,000 rpm
N = 26,000 rpm
Stall Limit
Data Based on Curves:
9675:64-036
-060
-061
-062
-063
-064
-065
-066
-067
Stall Limit from Curves:
9675:64-054
-082
$\frac{\Delta H}{N^2} \times 10^5 \frac{ft}{rpm^2}$
$\frac{Q}{N} \frac{gal}{rev}$
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
.18
.20
.22
.24
.26
.28
.30
.32
.34
.36
.38
.40
.42
.44
.46
.48
.50

Figure 46

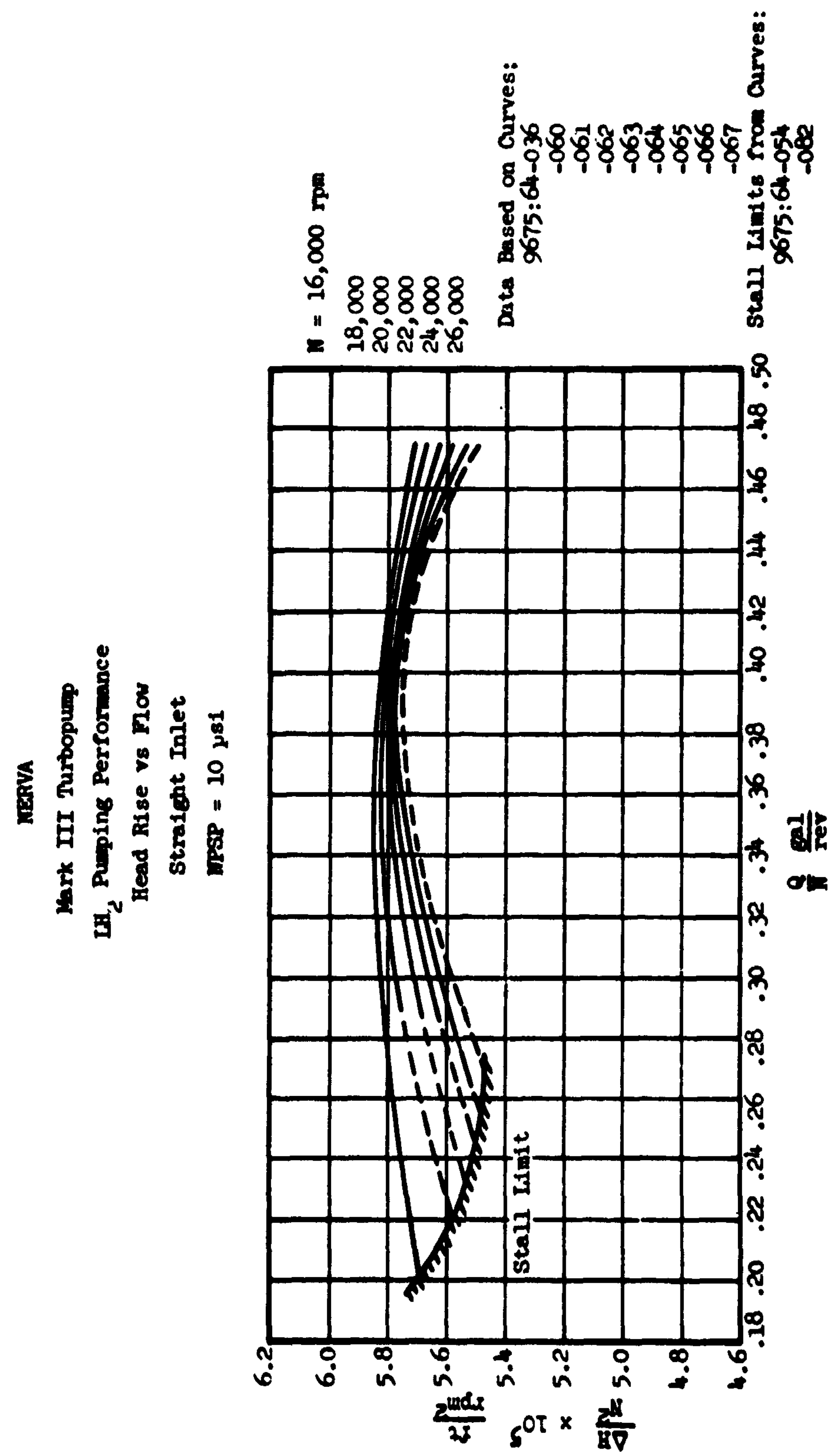

NERVA
Mark III Turbopump
LH_2 Pumping Performance
Head Rise vs Flow
Straight Inlet
NPSP = 10 psi
N = 16,000 rpm
18,000
20,000
22,000
24,000
26,000
Data Based on Curves:
9675:64-036
-060
-061
-062
-063
-064
-065
-066
-067
Stall Limits from Curves:
9675:64-054
-082
Stall Limit
$\frac{\Delta H}{N^2} \times 10^5 \frac{ft}{rpm^2}$
6.2
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
$\frac{Q}{N} \frac{gal}{rev}$
.18
.20
.22
.24
.26
.28
.30
.32
.34
.36
.38
.40
.42
.44
.46
.48
.50

Figure 47

NERVA

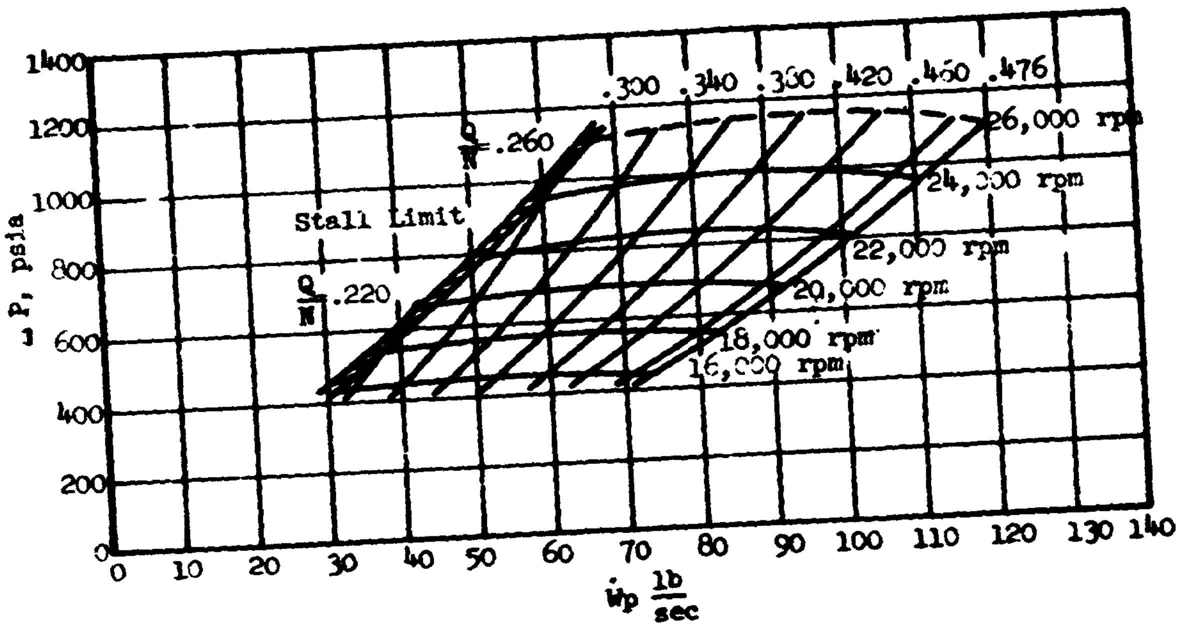
Mark III Turbopump

LH_2 Pumping Performance

Straight Inlet

NPSP = 10 psi

Inlet Specific Weight = 4.29 $\frac{lb}{ft^3}$



Data Based on Curves:
9675:64-0354
Stall Limit from Curves:
9675:64-054
9675:64-082

Figure 48

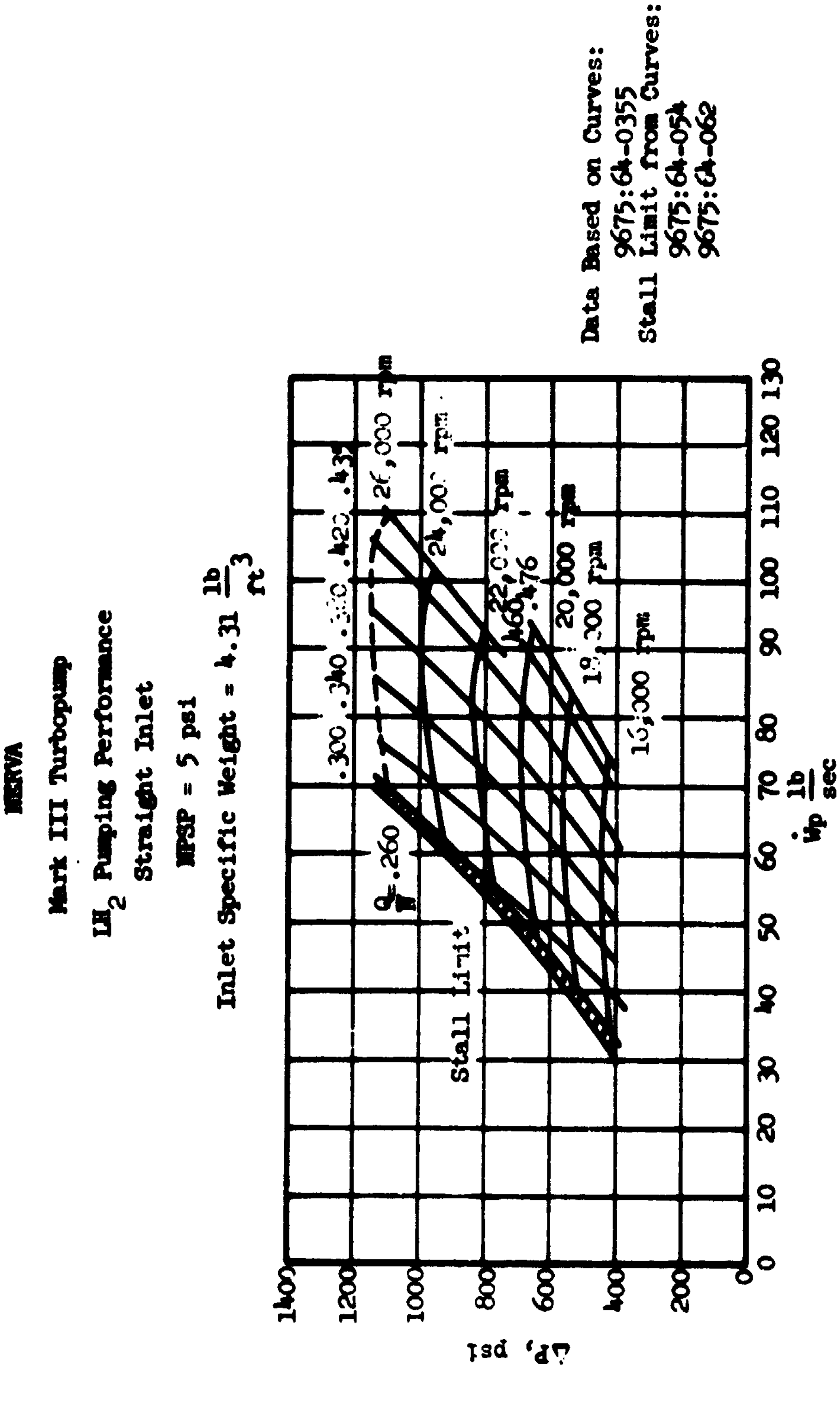


Figure 49

[redacted]

NERVA

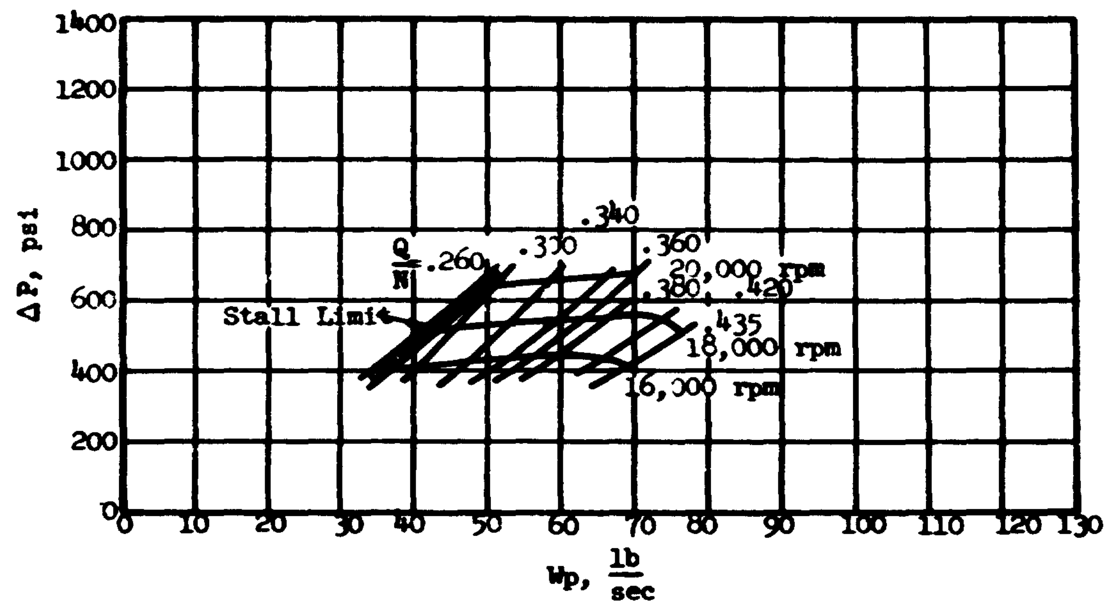
Mark III Turbopump

LH_2 Pumping Performance

Straight Inlet

NPSP = 2 psi

Inlet Specific Weight = 4.33 $\frac{lb}{ft^3}$



Data Based on Curves:
9675:64-0343
Stall Limit from Curves:
9675:64-054
9675:64-082

Figure 50

NERVA

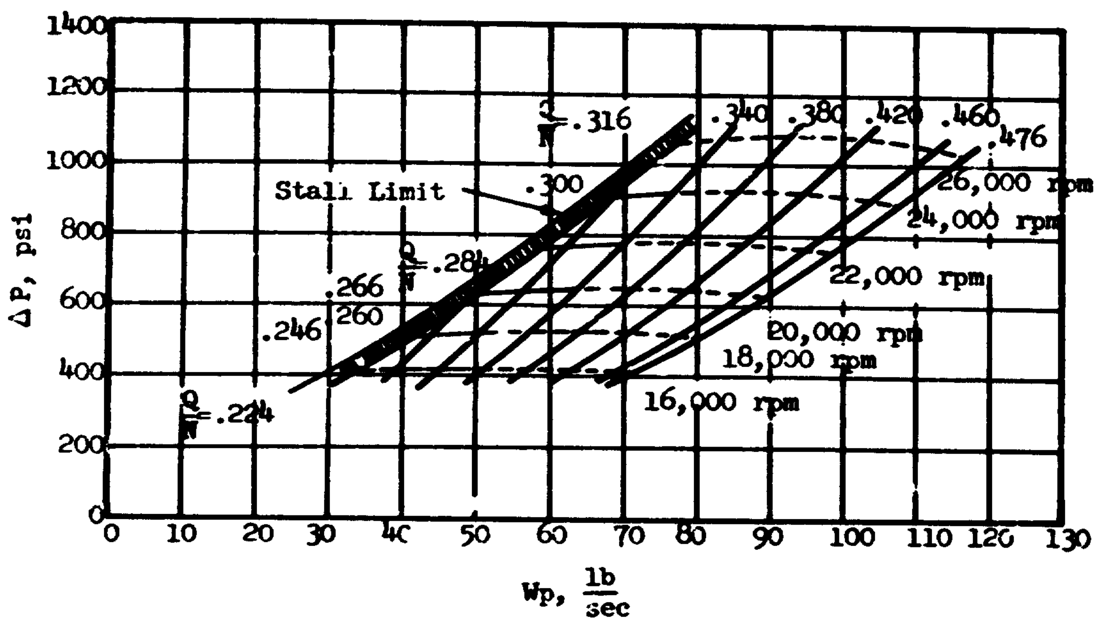
Mark III Turbopump

LH_2 Pumping Performance

Alternate 1, Gimbal Inlet

NPSP = 10 psi

Inlet Specific Weight = $4.29 \frac{lb}{ft^3}$



Data Based on Curves:
9675:64-0352
9675:64-0354
Stall Limit Based on Curves:
9675:64-054
9675:64-083

Figure 51

NERVA

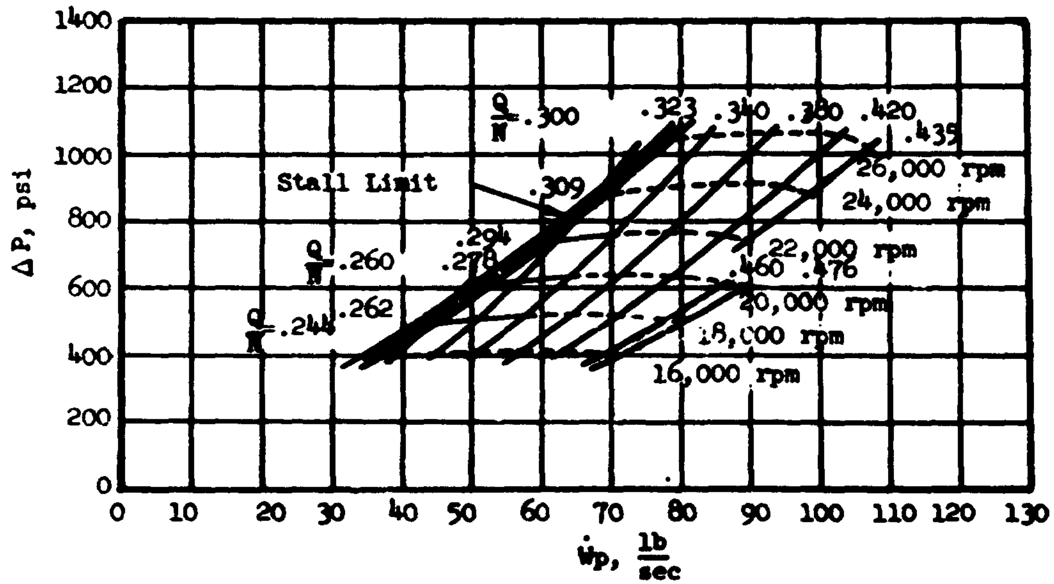
Mark III Turbopump

LH_2 Pumping Performance

Alternate 1, Gimbal Inlet

NPSP = 5 psi

Inlet Specific Weight = 4.31 $\frac{lb}{ft^3}$



Data Based on Curves:
9675:64-0352
9675:64-0355
Stall Limit Based on Curves:
3675:64-054
9675:64-083

Figure 52

NERVA

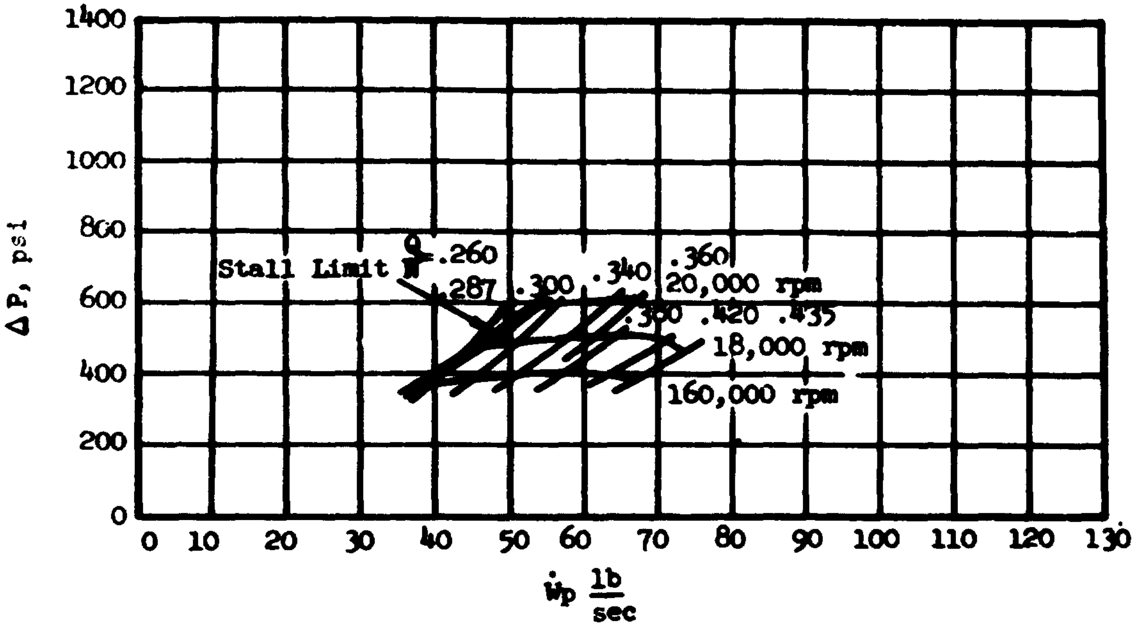
Mark III Turbopump

LH_2 Pumping Performance

Alternate 1, Gimbal Inlet

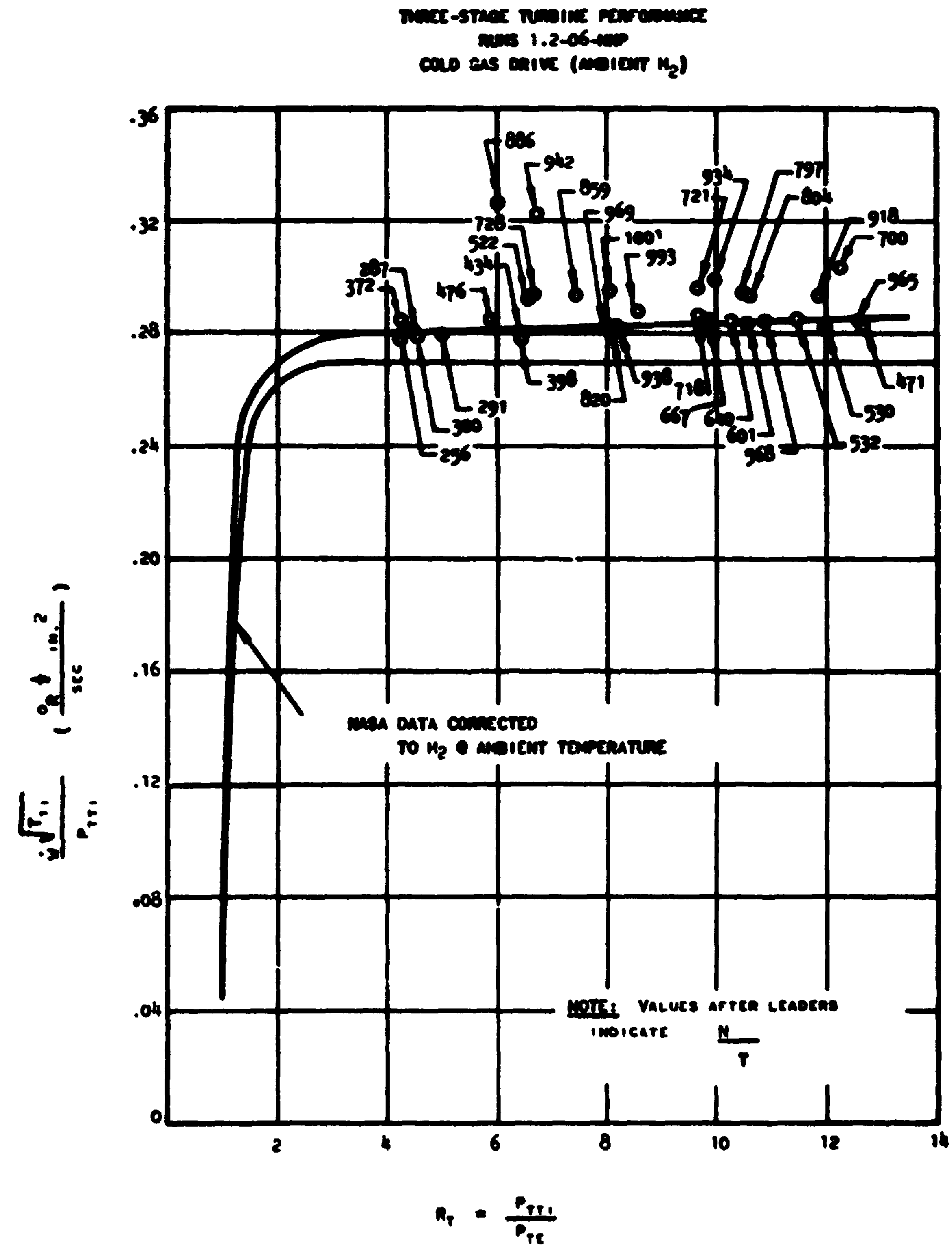
NPSP = 2 psi

Inlet Specific Weight = $4.33 \frac{lb}{ft^3}$



Data Based on Curves:
9675:64-0343
9675:64-0352
Stall Limit Based on Curves:
9675:64-054
9675:64-083

Figure 53



THREE-STAGE TURBINE PERFORMANCE
RUNS 1.2-06-HBP
COLD GAS DRIVE (AMBIENT H_2)
NASA DATA CORRECTED TO H_2 @ AMBIENT TEMPERATURE
NOTE: VALUES AFTER LEADERS INDICATE $\frac{N}{T}$
$R_T = \frac{P_{TTI}}{P_{TE}}$

Figure 54

NERVA MARK III
TWO-STAGE TURBINE PERFORMANCE
TEST SERIES 1.2-09-HHP

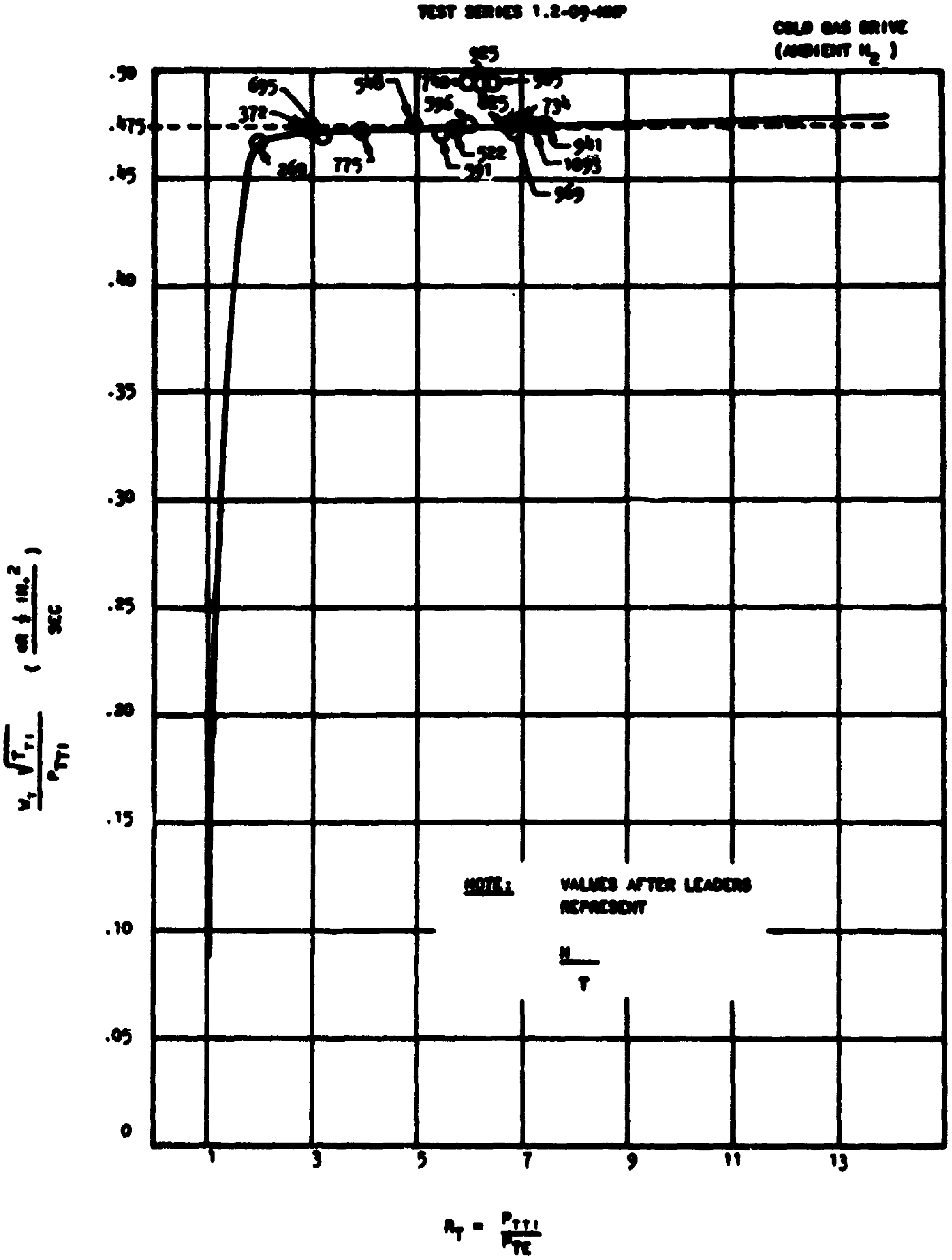


Figure 55

Third Generation Turbopump Three-Stage Turbine (u)

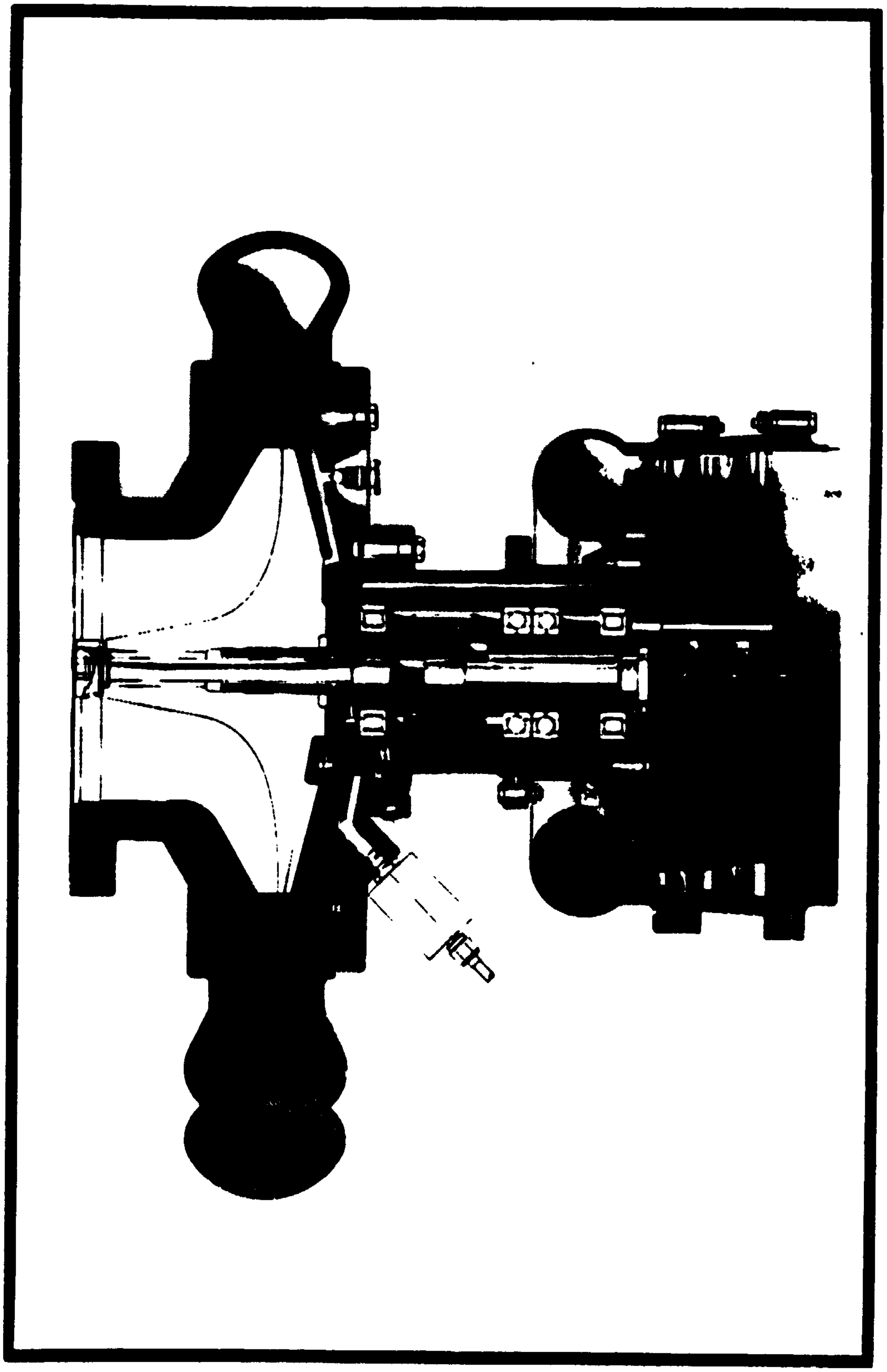


Figure 56

Mark III Turbopump Two-Stage Turbine (u)

PERFORMANCE PARAMETERS

SPEED (RPM)	24,000
PUMP-PRESSURE RISE (PSI)	1,000
PUMP INLET (NPSP)	2
TURBINE-INLET PRESSURE (PSIA)	450
TURBINE-INLET TEMPERATURE (°R)	1,140
TURBINE FLOW (LB/SEC)	5.7
OVERSPEED (RPM)	28,800
CRITICAL SPEED (RPM)	35,000
WEIGHT (LB)	350

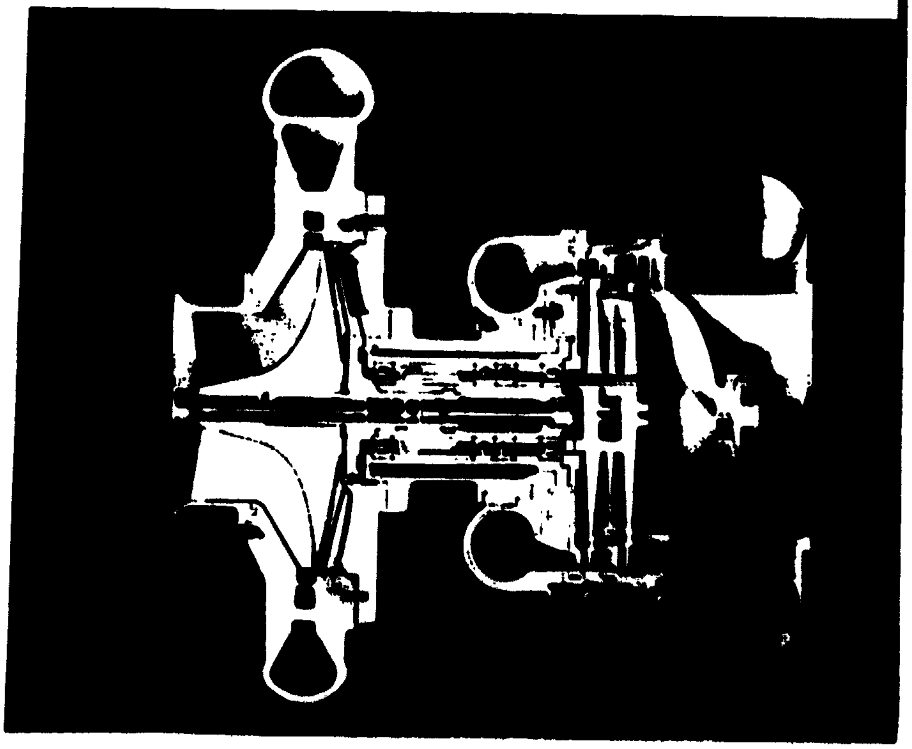


Figure 57

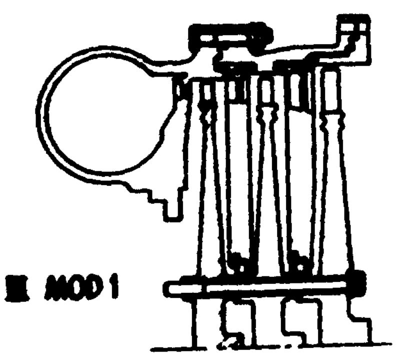
Turbine Power Increase Requirement

TPA SPECIFICATION

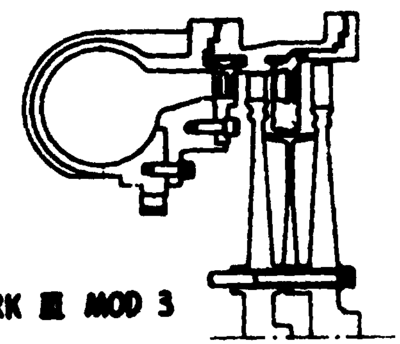
	NDC - 1A	MARK III MOD 3
P_{Td}, PSIA	765	1000
P_{Ti}, PSIA	515	450
T_{Ti}, °R	1140	1140
POWER, HP	5400	6800

SOLUTION OF PROBLEM

ELIMINATE FIRST-STAGE NOZZLE AND WHEEL



MARK III MOD 1



MARK III MOD 3

Figure 58

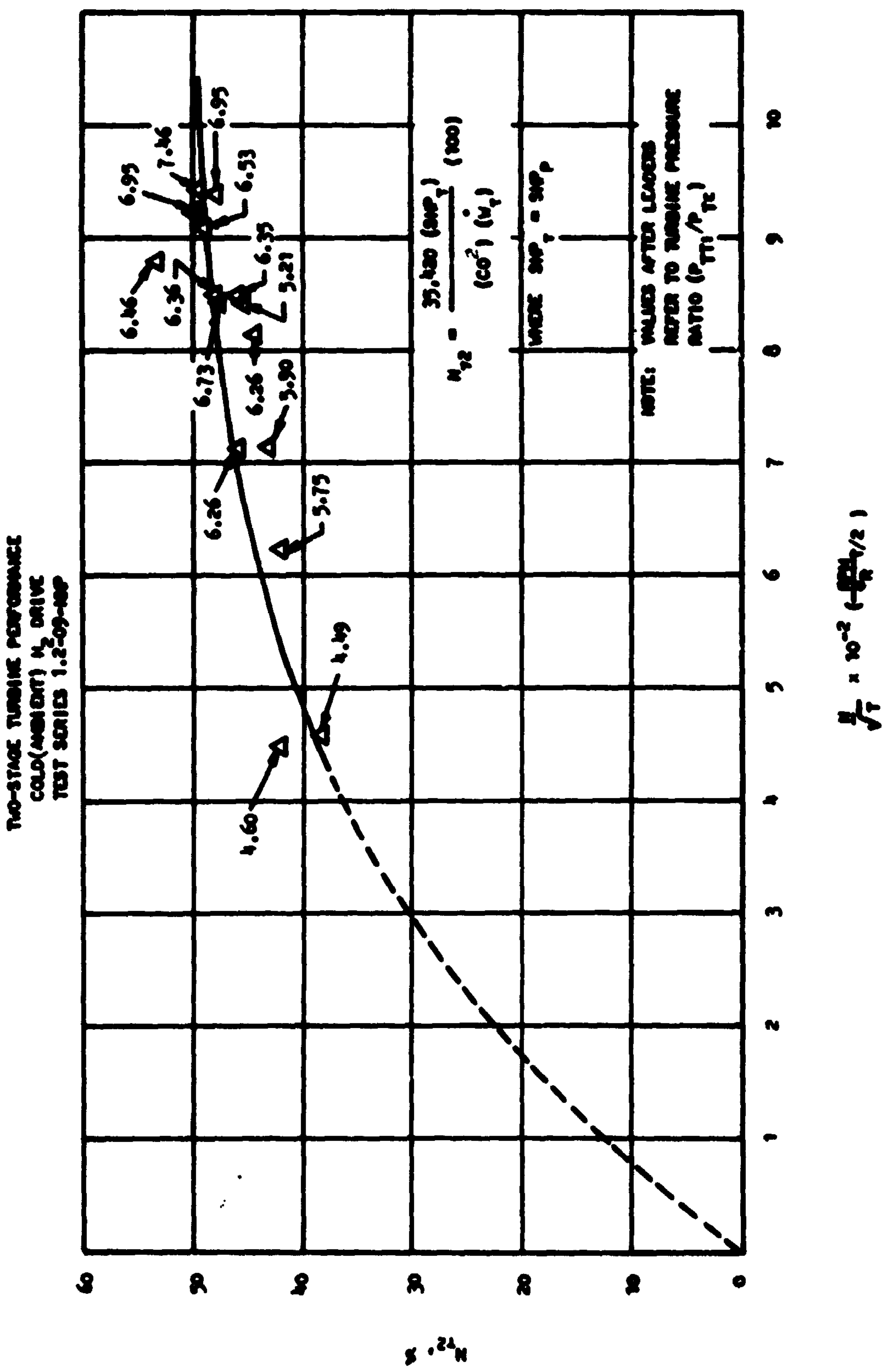

TWO-STAGE TURBINE PERFORMANCE
COLD(AMBIENT) N2 DRIVE
TEST SERIES 1.2-09-HP
NOTE: VALUES AFTER LEADERS REFER TO TURBINE PRESSURE RATIO
6.95
7.46
6.53
6.46
6.36
6.35
5.21
6.73
6.26
5.90
5.75
4.49
4.60
0
10
20
30
40
50
1
2
3
4
5
6
7
8
9
10

Figure 59

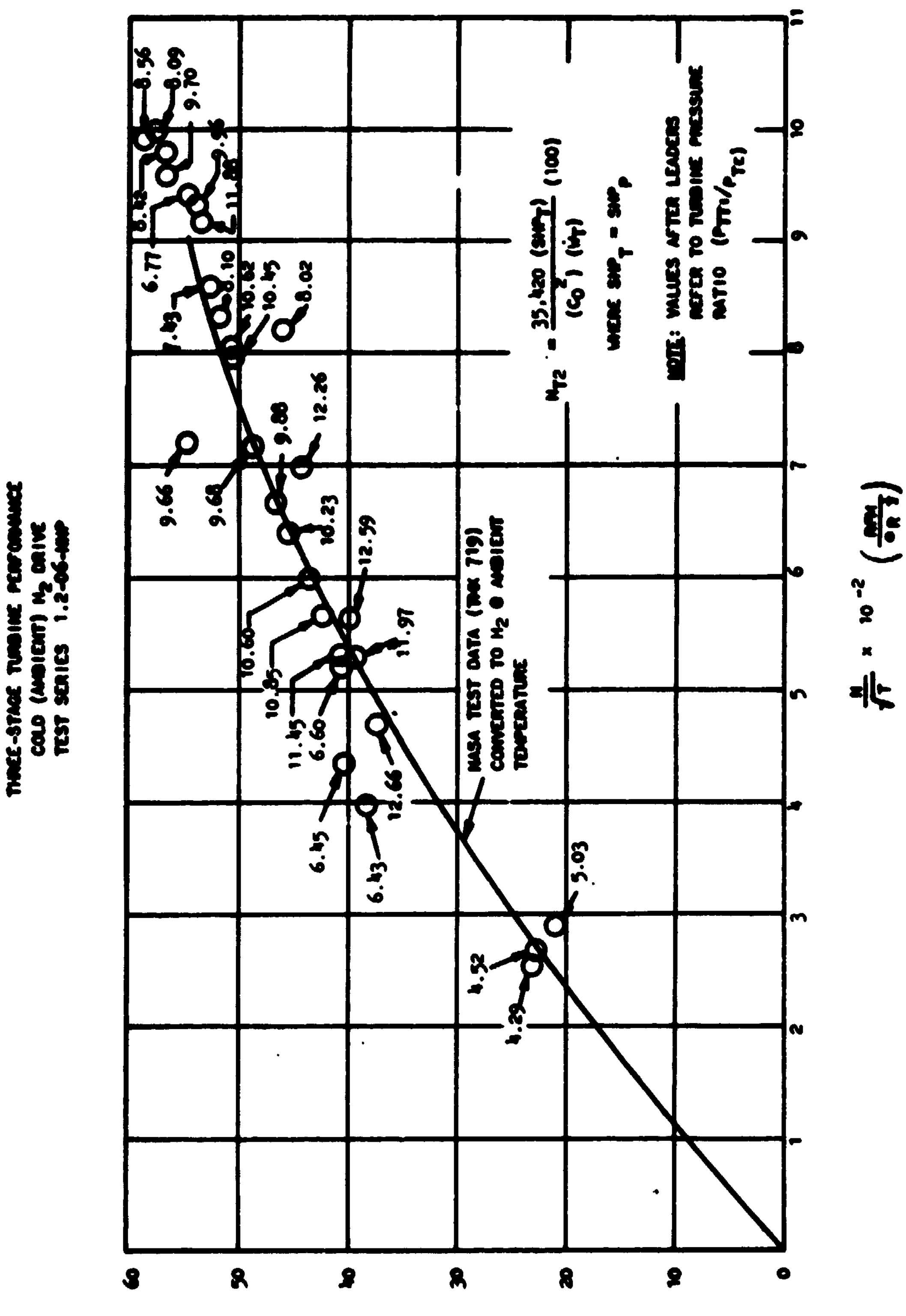

THREE-STAGE TURBINE PERFORMANCE
COLD (AMBIENT) H_2 DRIVE
TEST SERIES 1.2-06-HMP
$N_{T2} = \frac{35,420\ (SHP_T)}{(C_o^2)\ (W_T)}\ (100)$
WHERE $SHP_T = SHP_P$
NOTE: VALUES AFTER LEADERS REFER TO TURBINE PRESSURE RATIO (P_{TTI}/P_{TC})
NASA TEST DATA (TMX 719) CONVERTED TO H_2 @ AMBIENT TEMPERATURE
$\frac{N}{\sqrt{T}} \times 10^{-2}\ \left(\frac{RPM}{°R}\right)$

Figure 60

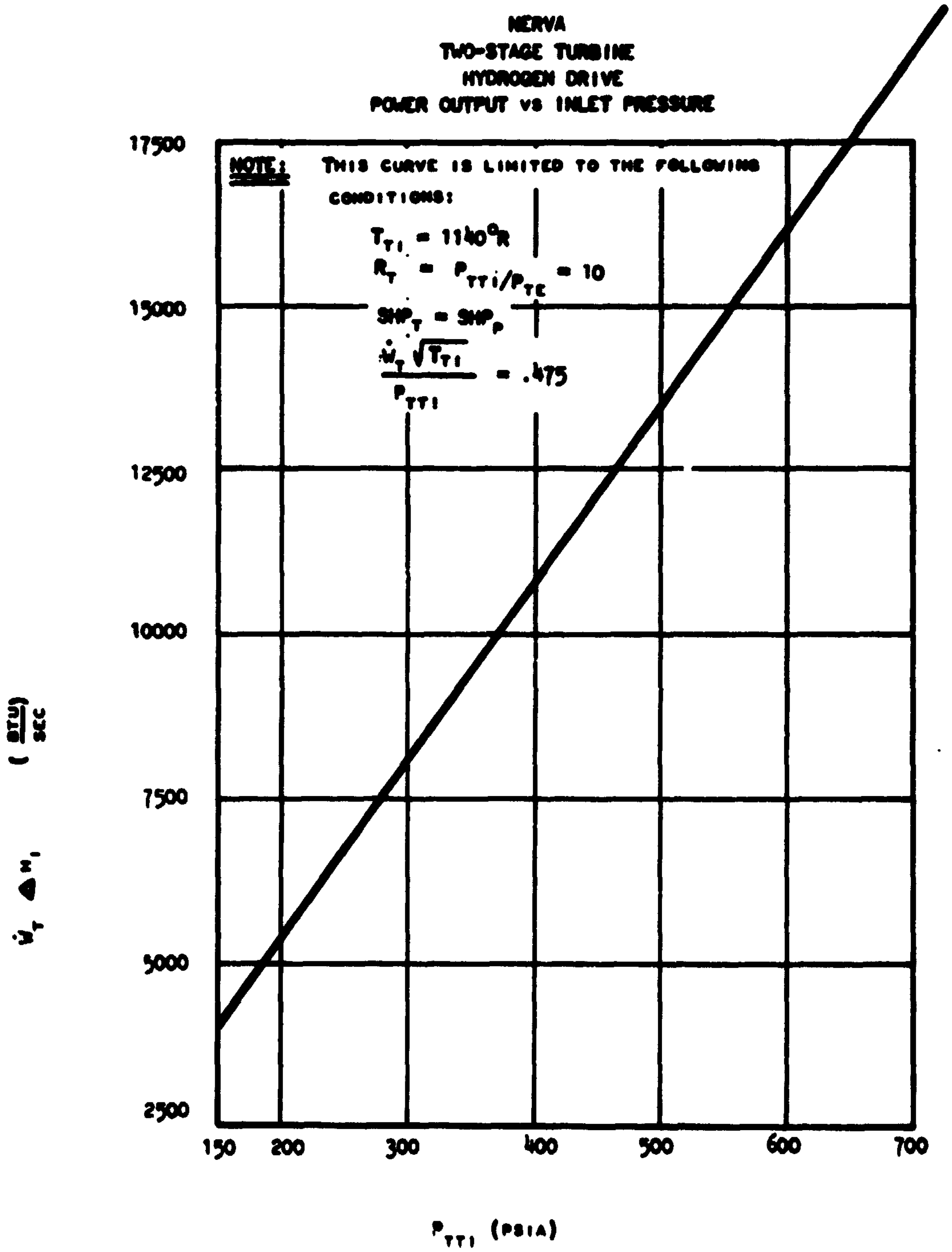

NERVA
TWO-STAGE TURBINE
HYDROGEN DRIVE
POWER OUTPUT vs INLET PRESSURE
NOTE: THIS CURVE IS LIMITED TO THE FOLLOWING CONDITIONS:
$T_{TI} = 1140°R$
$R_T = P_{TTI}/P_{TE} = 10$
$SHP_T = SHP_P$
$\frac{\dot{W}_T \sqrt{T_{TI}}}{P_{TTI}} = .475$
17500
15000
12500
10000
7500
5000
2500
150
200
300
400
500
600
700
$\dot{W}_T \Delta H_I$ (BTU / SEC)
P_{TTI} (PSIA)

Figure 61

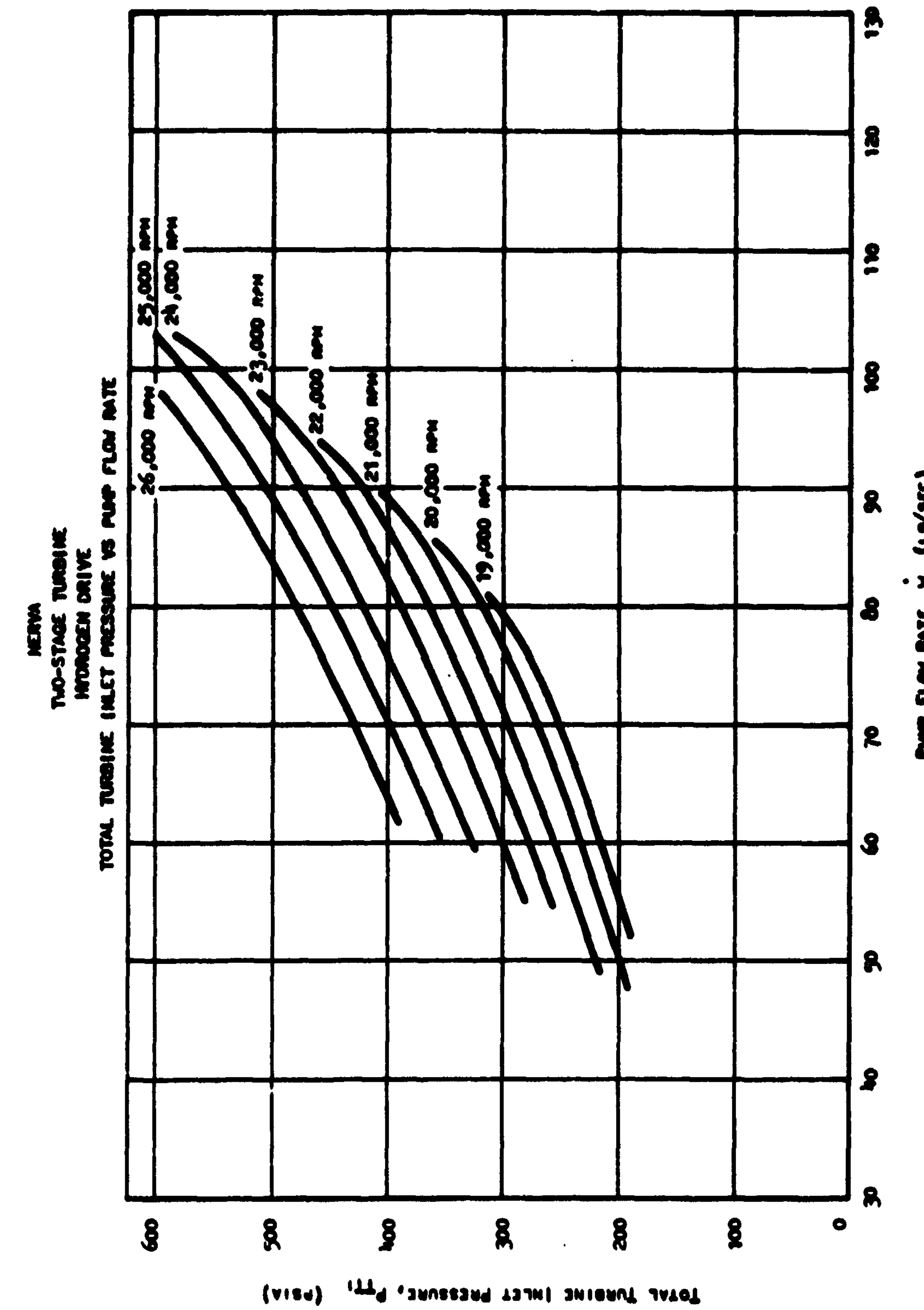

NERVA
TWO-STAGE TURBINE
HYDROGEN DRIVE
TOTAL TURBINE INLET PRESSURE VS PUMP FLOW RATE
26,000 RPM
25,000 RPM
24,000 RPM
23,000 RPM
22,000 RPM
21,000 RPM
20,000 RPM
19,000 RPM
600
500
400
300
200
100
0
TOTAL TURBINE INLET PRESSURE, P_{TI}, (PSIA)
30
40
50
60
70
80
90
100
110
120
130
PUMP FLOW RATE, $\dot{w}_p$ (LB/SEC)

Figure 62

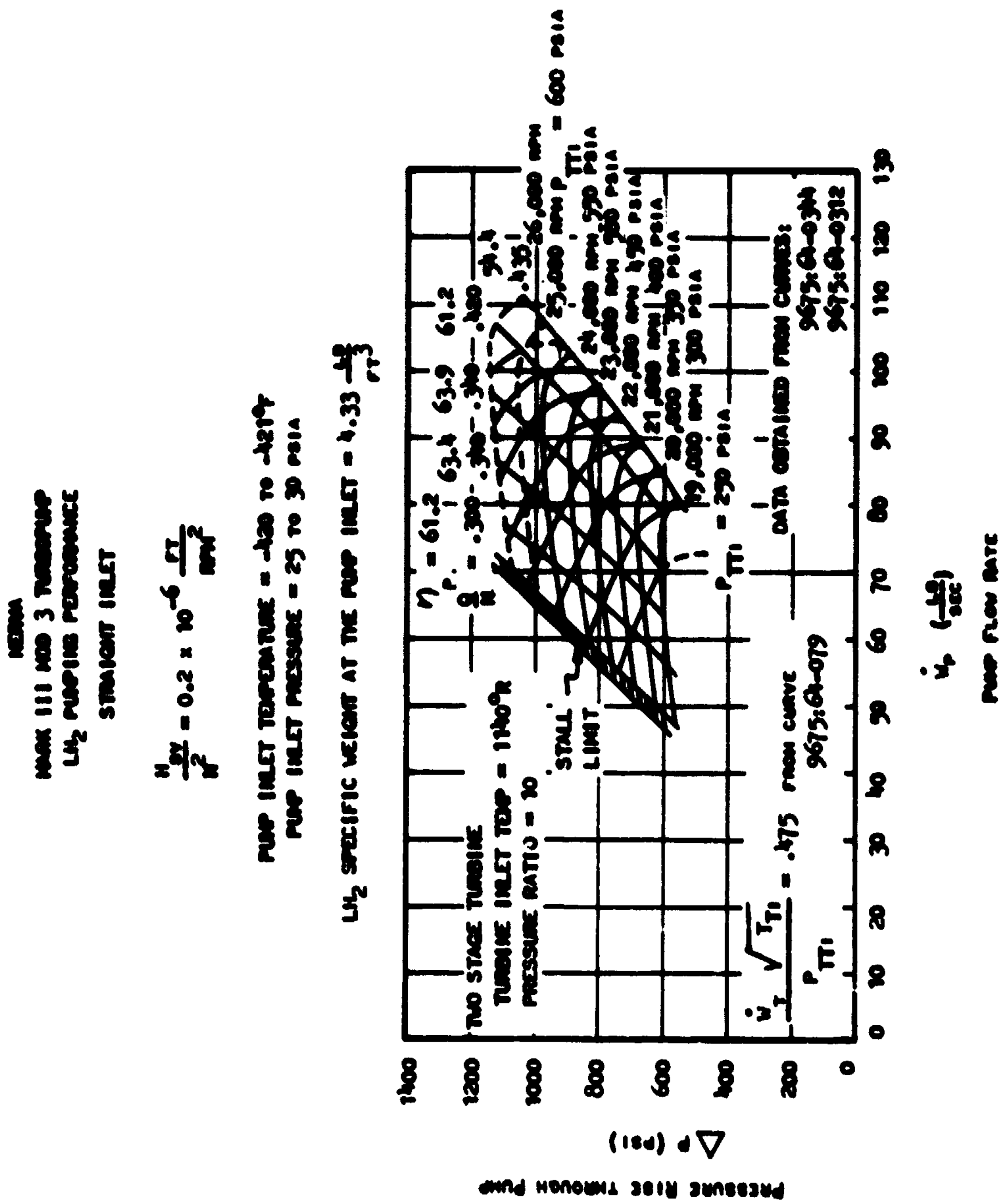
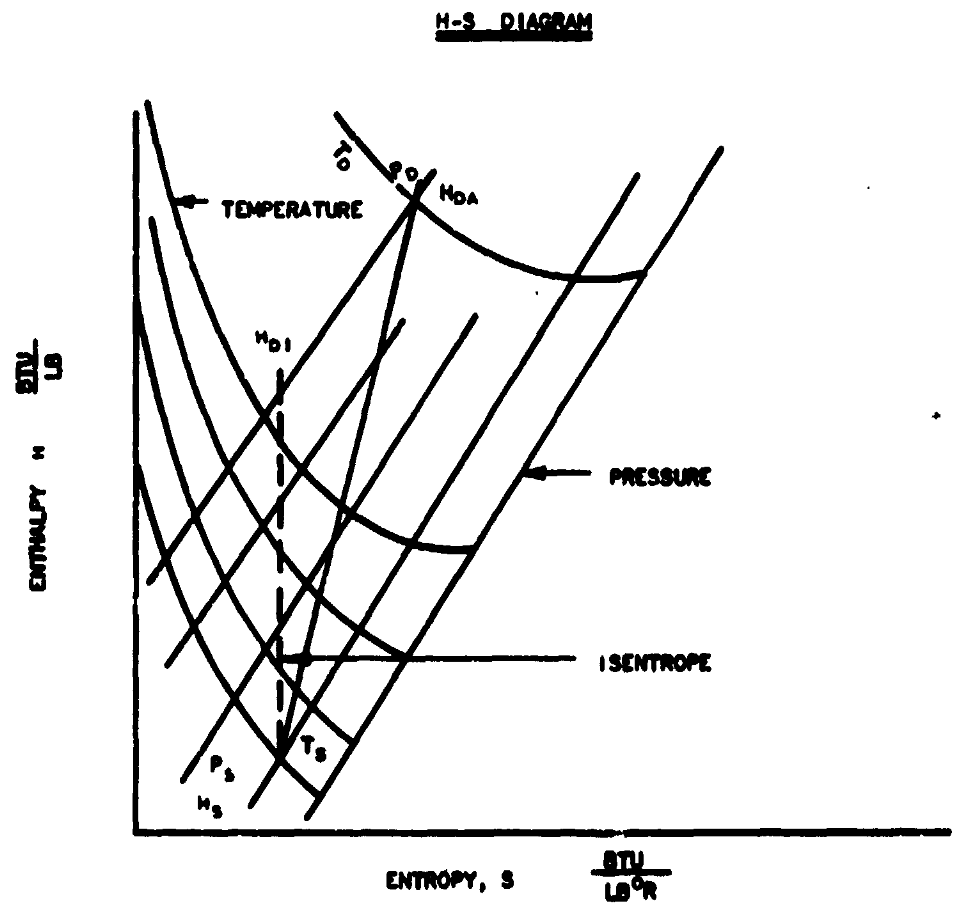

NERVA
MARK III MOD 3 TURBOPUMP
LH2 PUMPING PERFORMANCE
STRAIGHT INLET
PUMP INLET PRESSURE = 25 TO 30 PSIA
TWO STAGE TURBINE
PRESSURE RATIO = 10
STALL LIMIT
DATA OBTAINED FROM CURVES:
PUMP FLOW RATE
PRESSURE RISE THROUGH PUMP
ΔP (PSI)

Figure 63

APPENDIX B

PARAMETER DESCRIPTION AND METHODS OF CALCULATION

Parameter Description and Methods of Calculation



P_S = SUCTION PRESSURE

P_D = DISCHARGE PRESSURE

H_S = ENTHALPY AT SUCTION

H_{DI} = IDEAL DISCHARGE ENTHALPY

H_{DA} = ACTUAL DISCHARGE ENTHALPY

T_S = SUCTION TEMPERATURE

T_D = DISCHARGE TEMPERATUE

P_S, T_S, P_D, AND T_D ARE MEASURED PARAMETERS

H_S, H_{DI}, AND H_{DA} ARE DETERMINED FROM THE H-S DIAGRAM

Symbol	Parameter Description	Units
h	Enthalpy	Btu/lb
ΔH	Head rise	ft
H_{sv}	Net positive suction head	ft
N	Speed	rev/min
η_p	Pump efficiency	
η_t	Turbine efficiency	
Q	Volumetric flow	gal/min
P	Pressure	psi
R_t	Turbine pressure ratio	
SHP	Shaft horsepower	HP
T	Temperature	°F, °R
W_p	Pump flow rate	lb/sec
W_t	Turbine flow rate	lb/sec

Symbol	Method of Calculation	Units
ΔH	$778.2\,(h_{di}-h_s)$	ft
H_{sv}	$144\,(SVS)\,(P_s-P_{vp}) + \frac{ECPS}{12} + \frac{1}{2(32.174)}\left[\frac{144\,W_p\,(SVS)}{A_s}\right]^2$	ft
	Where A_s = Suction area	in.^{2}
	ECPS = Elevation correction	
	P_s = Suction pressure	psia
	P_{vp} = Vapor pressure	psia
	SVS = Specific volume at suction	$\frac{ft^3}{lb}$
η_p	$\frac{h_{di}-hs}{h_{da}-h_s}\,(100)$	
η_T	$\frac{35,420\,(SHP)}{(Co)^2\,(\dot{W}_t)}\,(100)$	
	where Co = Isentropic spouting velocity	$\frac{ft}{sec}$

Symbol	Method of Calculation	Units
R_t	$\frac{P_{TTi}}{P_{Te}}$	
	where P_{TTi} = Total turbine inlet pressure	psia
	P_{Te} = Static turbine exhaust pressure	psia
SHP	$\frac{FHP \times 100}{\eta_P}$	HP
	Where $FHP = \frac{W_p \Delta H}{550}$	HP
W_p	$\frac{Q}{448.86\ (SVD)}$	$\frac{lb}{sec}$
	where SVD = Specific volume at discharge	$\frac{ft^3}{lb}$

APPENDIX C

IMPELLER AND HOUSING TEST HISTORY

Test Series	Test No.	TPA P/N	TPA S/N	Impeller P/N	Impeller S/N	Hsg P/N	Hsg S/N
1.2-04-NMP	001	258000-120	061	269373-1	065	258083-9	0001912
	002	258000-120	061	269373-1	065	258083-9	0001912
	003	258000-120	061	269373-1	065	258083-9	0001912
	004	258000-120	061	269373-1	065	258083-9	0001912
1.2-06-NMP	001	265800-49	063	263043-1	061	258083-29	0001911
	002	265800-49	063	263043-1	061	258083-29	0001911
	003	265800-4[illegible]	063	263043-1	061	258083-29	0001911
	004	265800-49	062	263043-1	067	258083-29	0000177
	005	265800-89	063	263043-1	061	258083-29	0001911
	006	265800-89	063	263043-1	061	258083-29	0001911
	007	265800-89	063	263043-1	061	258083-29	0001911
	008	265800-89	063	263043-1	061	258083-29	0001911
	009	265800-99	062	263043-1	067	258083-29	0000177
	010	265800-99	062	263043-1	067	258083-29	0000177
	011	265800-99	062	263043-1	067	258083-29	0000177
2106 sec all	012	265800-109	063	263043-1	061	258083-29	0000177
runs - above	013	265800-109	063	263043-1	061	258083-29	0000177
20 K 461 sec	014	265800 BU 5	063	263043-1	061	258083-29	0000177
all runs	015	265800 BU 5	063	263043-1	061	258083-29	0000177
	016	265800 BU 5	063	263043-1	061	258083-29	0000177
	017	265800 BU 5	063	263043-1	061	258083-29	0000177
330 sec - 703	018	265800-119	062	294333-1	067	258083-19	0000177
sec all runs -	019	265800-119	062	294333-1	067	258083-19	0000177
257 above all							
1.2-08-NMP	001	278000-79	067	263043-1	0620	258083-29	0001913
	002	278000-29	067	263043-1	0620	258083-29	0001913
	003	278000-89	066	263043-1	0521	258083-29	0000179
	004	278000-89	066	263043-1	0521	258083-29	0000179
	005	278000-79	065	263043-1	0533	258083-29	0000420
	006	278000-79	066	263043-1	0521	258083-29	0000179
	007	278000-79	066	263043-1	0521	258083-29	0000179
	008	278000-[illegible]9	066	263043-1	0521	258083-29	0000179
	009	278000-79	066	263043-1	0521	258083-29	0000179
1.2-00-NMP	001	278000-109	063	263043-1	0534	258083-29	0001911
	002	278000-109	063	263043-1	0534	258083-29	0001911
	003	278000-109	063	263043-1	0534	258083-29	0001911
	004	278000-109	063	263043-1	0534	258083-29	0001911
	005	278000-109	063	263043-1	0534	258083-29	0001911
	006	278000-109	063	263043-1	0534	258083-29	0001911
	007	278000-109	063	263043-1	0534	258083-29	0001911
	008	278000-109	063	263043-1	0534	258083-29	0001911
	009	278000-129	065	263043-1	0533	258083-29	0001911
	010	278000-129	065	263043-1	0533	258083-29	0001911
	011	278000-129	065	263043-1	0533	258083-29	0001911
	012	278000-129	065	263043-1	0533	258083-29	0001911
	013	278000-129	065	263043-1	0533	258083-29	0001911
	014	278000-129	065	263043-1	0533	258083-29	0001911